3 1761 03568 2368

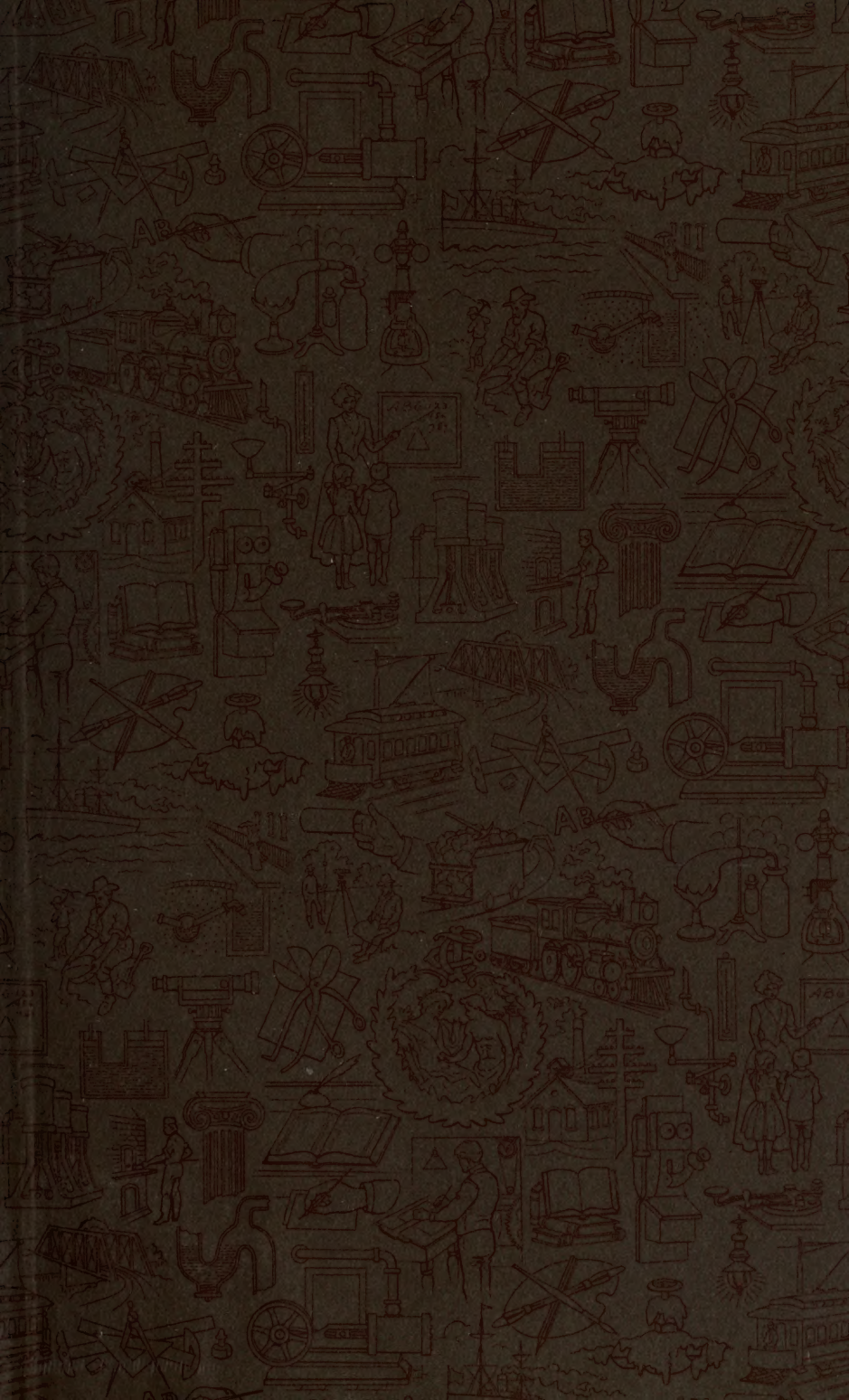
*Presented to the*

LIBRARY *of the*

UNIVERSITY OF TORONTO

*by*

**JAMES W. PUDDY**



A TEXTBOOK

ON

# ELECTRIC STREET-CAR RUNNING

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

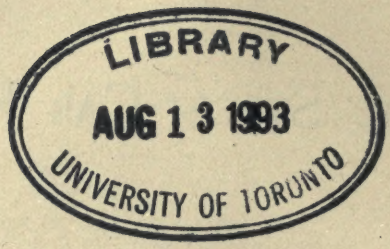
---

MOTOR PRINCIPLES
CAR EQUIPMENT

---

2886

SCRANTON
INTERNATIONAL TEXTBOOK CO.
A-3




Copyright, 1901, by THE COLLIERY ENGINEER COMPANY, under the title of
A TREATISE ON ELECTRIC STREET-CAR RUNNING.

Entered at Stationers' Hall, London.

Motor Principles: Copyright, 1899, by THE COLLIERY ENGINEER COMPANY.
Car Equipment, Parts 1 and 2: Copyright, 1899, by THE COLLIERY ENGINEER COMPANY.
Car Equipment, Parts 3, 4, 5, 6, 7, and 8: Copyright, 1900, by THE COLLIERY ENGINEER COMPANY.
Car Equipment, Parts 9 and 10: Copyright, 1901, by THE COLLIERY ENGINEER COMPANY. Entered at Stationers' Hall, London.

All rights reserved.

*c1*
Press of EATON & MAINS
NEW YORK

# PREFACE.

The Bound Volumes sent to students of the Electric Street-Car Running Course are two in number. The first volume contains twelve papers, the first two of which take up the principles involved in the operation of dynamos and motors; the remainder describe the various appliances used for the operation and equipment of electric street cars. The second volume is practically a continuation of the first, and contains seven sections, giving general instructions relating to car operation and detailed instructions covering the subject of brakes.

This course has been prepared to provide thorough and systematic instruction relating to the equipment and operation of electric street cars. Heretofore, very little on this subject has been published in connected form and put in such shape as to be easily understood by those who have not had previous technical training. The course, as here presented, is the result of years of practical experience in the actual operation of electric railways. It describes plainly how to locate and remedy faults of various kinds, and illustrations have been freely used to make the text as clear as possible.

If the student masters thoroughly the instruction here given, he should be able to understand and operate any other equipment he may be placed in charge of. The text is arranged so as to be easily understood, mathematics is entirely eliminated, and the course should prove of great assistance to all those in need of straightforward practical instruction on the equipment and operation of electric street cars.

The method of numbering the pages, cuts, articles, etc. is such that each paper and part is complete in itself; hence, in order to make the indexes intelligible, it was necessary

to give each paper and part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number, it is preceded by the printer's section mark §. Consequently, a reference such as § 14, page 12, would be readily found as follows: Look through the volume, along the headlines, until § 14 is found, and then through § 14 until page 12 is found.

The Examination Questions have been divided into sections to which have been given the same section numbers as the Instruction Papers to which they belong, and are grouped together at the end of the volumes containing the Instruction Papers to which they refer.

INTERNATIONAL CORRESPONDENCE SCHOOLS.

# CONTENTS.


| | Section. | Page. |
|---|---|---|
| **Motor Principles, Part 1.** | | |
| Electrical Units | 1 | 1 |
| Ohm's Law | 1 | 9 |
| The Magnet | 1 | 11 |
| The Electromagnet | 1 | 14 |
| Motors | 1 | 19 |
| **Motor Principles, Part 2.** | | |
| Motors and Dynamos | 2 | 1 |
| Handling Motors | 2 | 9 |
| Induction | 2 | 19 |
| **Car Equipment, Part 1.** | | |
| Car Appliances | 3 | 1 |
| The Trolley | 3 | 2 |
| Trolley Stands | 3 | 7 |
| Trunk Wiring | 3 | 22 |
| Canopy Switches | 3 | 25 |
| Fuse Boxes | 3 | 33 |
| **Car Equipment, Part 2.** | | |
| The Lightning Arrester | 4 | 1 |
| General Remarks on Lightning Arresters. | 4 | 15 |
| Resistance Coils | 4 | 25 |
| Shunts | 4 | 31 |

| | Section. | Page. |
|---|---|---|
| **Car Equipment, Part 3.** | | |
| Controllers and Wiring | 5 | 1 |
| Rheostat Method | 5 | 1 |
| Remarks on The Use of Shunts | 5 | 12 |
| General Remarks on Loops | 5 | 17 |
| Grounds | 5 | 23 |
| **Car Equipment, Part 4.** | | |
| Old Rheostat Control | 6 | 1 |
| Dead Rails | 6 | 19 |
| Open Circuit in Armature | 6 | 22 |
| Open Circuit in Field | 6 | 24 |
| **Car Equipment, Part 5.** | | |
| Old Rheostat Single Motor Control | 7 | 1 |
| Old Rheostat Multiple Control | 7 | 14 |
| Old Rheostat Series Control | 7 | 45 |
| **Car Equipment, Part 6.** | | |
| General Electric 1000 Motor | 8 | 1 |
| General Electric 52 Motor | 8 | 33 |
| General Electric 800 Motor | 8 | 42 |
| **Car Equipment, Part 7.** | | |
| General Electric Controllers | 9 | 1 |
| The K2 Controller | 9 | 3 |
| The K11 Controller | 9 | 45 |
| **Car Equipment, Part 8.** | | |
| Westinghouse No. 3 Motor | 10 | 1 |
| Westinghouse 12A Motor | 10 | 16 |
| Westinghouse Controllers | 10 | 20 |
| **Car Equipment, Part 9.** | | |
| The Walker System | 11 | 1 |
| Walker 30 Horsepower Motor | 11 | 1 |
| Walker Type S Controller | 11 | 13 |

| Car Equipment, Part 10. | *Section.* | *Page.* |
|---|---|---|
| The Johnson Company's System | 12 | 1 |
| The No. 20 Motor | 12 | 1 |
| The No. 34 Motor | 12 | 8 |
| The Johnson Controllers | 12 | 13 |
| The No. 34 Controller | 12 | 13 |

# MOTOR PRINCIPLES.

(PART 1.)

## ELECTRICAL UNITS.

**1.** Such expressions as *line pressure*, *line voltage*, *volts on the line*, etc. are more or less well known to every one, but many people have little idea of what they mean, further than to have a feeling that they are very good expressions to associate with all kinds of shocks and fatal electrical accidents. Now, without *units*, or *standards*, of some kind, it would be almost impossible to talk about quantity. Before the adoption of our units and standards of measure, men used such units as, *as much as a horse can carry; as far as a man can walk in a day.* They spoke of so many moons or so many suns when they alluded to some past or future event. Men have always had to have some kind of unit with which to measure. The pint, quart, and gallon are units of liquid measure, and without these, or others, one could not talk reasonably about the quantity of water contained in a vessel. The pound (lb.) is the unit of weight, and, naturally, becomes the unit of pressure whatever that pressure may be due to—whether directly to a weight, as in a gas reservoir; or to steam, as in a boiler; or to air or oil or water confined in a tank acted on by a pump. When we speak of the boiler pressure being 50 pounds, we mean 50 pounds per square inch, and if we could conceive of a boiler full of men, each man with a crowbar pressing outwardly against each square



For notice of the copyright, see page immediately following the title page.

inch of boiler surface with a force of 50 pounds, we would have the same conditions we have, were the boiler under 50-pounds steam pressure. To talk of quantity of any kind, then, one must use generally understood units or standards.

## VOLTAGE.

### THE VOLT.

**2.** The *unit of voltage*, or *potential difference*, or *electromotive force*, is the *volt*, so called in honor of a man named Volta.

**3. Analogy.**—If pressure gauges be placed on the suction and exhaust sides of a pump in action, these gauges will show very different pressures to exist on the two sides of the pump, and the difference is due to the action going on inside the pump. The pump has not generated any water or air, as the case may be; it has simply raised the *pressure* of air or water that already existed. If we place an electrical-pressure gauge, or **voltmeter,** across from the trolley wire, called the *positive* side and marked +, to the rail, called the *negative* side and marked −, of any street-railway system, the gauge will show, in *volts*, the difference in electrical pressure between the two sides of the circuit. This difference is due to the action taking place inside an electrical machine called a *dynamo*, situated in the power house. The dynamo does not generate electricity any more than the pump generates water; it merely raises the pressure.

**4. Pump and Dynamo.**—In Fig. 1, $A$ is the piston of a single-acting pump (by single-acting pump is meant one that takes in water at only one end of the stroke) driven through rods $R$ and $K$ by means of an engine not shown. Piston $A$ moves in cylinder $F$; water sucked up from tank $G$ through pipe $T$ is ejected from pipe $T'$, and falls back into tank $G$, to be again raised. Gauges at $V$ and $V'$ show the pressures on

the suction and exhaust sides of the pump, and the difference in these pressures, the fall in pressure through the pump, is expressed in pounds per square inch. In Fig. 2, $A$ is the armature or pressure generator of a dynamo situated in the station not shown; $T$ is the positive, or exhaust, or trolley-wire, side of the machine; $G$ is the negative, or suction, or rail, side of the machine; $V$ is a voltmeter that shows the line voltage or difference in electrical pressure between the positive and the negative sides of the circuit; or, as this

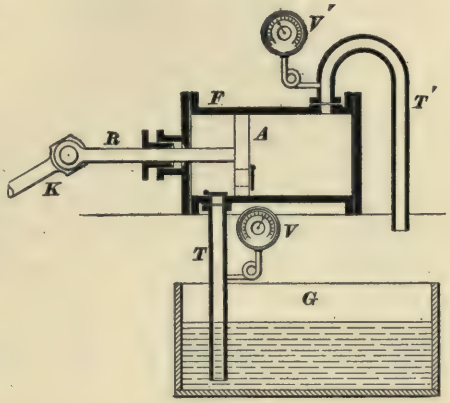



FIG. 1.

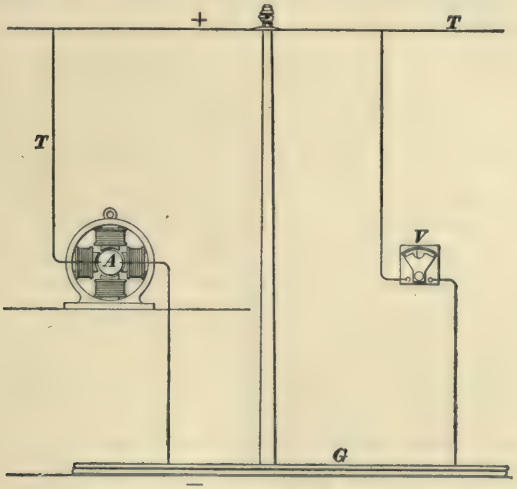



FIG. 2.

difference is commonly called, the trolley voltage, and expresses its value in volts. This analogy is carried thus

far to show how closely related in principle are the pump with its water pressure and the dynamo with its electrical pressure, as regards general action.

**5. Application of the Volt.**—As illustrations of the every-day use of the term *volt*, note the following: A city street-railway circuit generally carries a pressure of from 475 volts to 525 volts; suburban lines, 600 volts or more; the voltage across an arc lamp ranges from 40 to 50 volts, according to the candlepower of the lamp; a circuit of 100 lamps would, therefore, have a voltage of 5,000 across the two ends of the circuit; across an incandescent lamp, generally about 110 volts; a bell-circuit cell, 1 volt; a storage cell, 2 volts. Nearly 2,000-volts pressure is used in the electric chair, but 500-volts pressure has been known to prove fatal, and with good contact, 100-volts pressure applied continuously will cause a person to become insensible. Different people can stand different pressures, long thin people seeming to be less inconvenienced than short plump ones. Fifty volts will kill a mule.

## CURRENT.

### THE AMPERE.

**6.** The unit of current strength is the **ampere,** named after a man famous for his electrical work.

**7. Analogy.**—One hears of the electric current, and, being more or less acquainted with some of its uses, naturally tries to form some mind picture of a definite quantity of electricity moving at a definite rate; no definite idea of quantity can be formed, for there is no definite idea of the thing itself. True, some theories have been advanced as to the nature of electricity, but these are not clear to most minds, and it is safe to say that no one has ever answered,

nor can any one answer, the question, What is electricity? Its effects, however, have been closely studied, and, as a result of this study, it is a known fact, that when electricity moves, it moves very quickly, and it is the rate of flow that concerns us most. To intelligently handle the subject of the rate of flow of electricity, it is necessary to have a well defined and commonly accepted unit. *Rate of flow* and *strength of current* mean the same thing, just as in the case of water flowing in a pipe; the gallons per minute or rate of flow of the water would be an expression of the strength or volume of the current flowing in the pipe.

**8. Effects of Current.**—Imagine a current to be flowing in a wire; this current will have a strength governed by conditions to be named later, and will show its presence in the wire by certain effects, viz.: The wire will heat, as shown by the electric car heater, which is nothing more than a series of wires so disposed that the current can pass through them and heat them without danger to the car or to persons' clothes; if the current is strong enough, the wire will get white-hot and give off light just as the street-car lamps do; if the current gets too strong, the wire reaches its melting temperature and blows, just as a car fuse blows when the power is fed in too fast on a grade, or when a controller or some device under the car is grounded; again, the wire carrying the current will be able to attract or repel other wires carrying a current, as we shall soon see, and *on this effect depends all motor action.* If allowed to pass through solutions of some substances, the electric current will decompose the solution into its elements. For example: The salt called *nitrate of silver* is a well known salt, that blackens the skin wherever it touches it. Nitrate-of-silver solution can be made by dropping a silver dime into a glass of nitric acid; true, this will not make a pure solution of silver nitrate, because a silver dime has copper in it, but it will do for illustration. This principle of decomposition of solutions by an electric current is the principle selected for determining the ampere in definite terms, and a brief talk on

how it is done will not be out of place here. In Fig. 3, $V$ is a glass vessel to hold the nitrate solution. $C$, $C$ are two ordinary two-way connectors, such as are used for connecting the motors under a car, and they are used here to serve the double purpose of supporting $M$ and $N$ and of receiving the leads from $B'$, the battery that furnishes the current. $M$ is a piece of pure silver, and $N$ is an article to be plated. $D$ is a strip of wood perforated to receive stems attached to $M$ and $N$, and also serves to insulate $M$ from $N$.

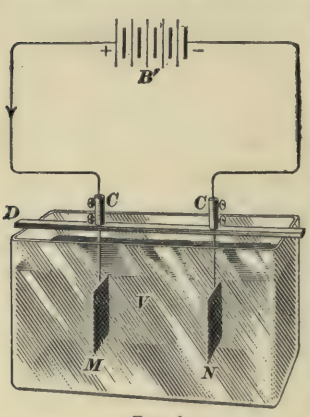


FIG. 3.

When a current is passed through a solution, silver is deposited on plate $N$, and is taken off plate $M$. A current of a given strength will, in a given time, deposit a certain amount of silver on plate $N$. That current which in 1 second will deposit .001118 of a gram of silver on $N$ is called an **ampere.** That current which would deposit 1 pound of silver on $N$ in 1 second might have been taken as the unit of current, but a unit so large would make it necessary to express the values of currents, with which we ordinarily deal, as fractions, and this would be a very bad feature.

**9. Application of the Ampere.**—Each lamp circuit on a street car takes a current of about one-half an ampere. A 20-foot car equipped with a pair of up-to-date 30-horse-power motors will, on a level and at full speed, take a current of about 30 amperes. A single-heater circuit requires from 3 to 15 amperes of current, according to the make and capacity of the heater, and according to the notch upon which the heater handle rests. Arc-light circuits run usually from about 6 amperes to 10 amperes, according to the capacity and the make of the lamp. The ampere bears the same relation to an electrical circuit that gallons per minute bear to a pipe line.

## RESISTANCE.

### THE OHM.

**10.** The unit of resistance is the **ohm,** also named after a famous man.

**11. Analogy.**—When a water pipe becomes clogged with mud, not as much water will pass in a given time as when the pipe is clear. The obstruction, whatever it may be, resists the flow of the water; or, the obstruction *offers resistance* to the flow of water. If the diameter of a pipe carrying water is decreased, or if the length of the pipe is increased, the flow of water becomes less, because the resistance to the flow has been made greater. So far, the same facts hold good in an electrical circuit. Every electrical circuit has a certain amount of resistance; if it did not, a very small electrical pressure could send a very large current through it. If we decrease the diameter of the wire in a circuit, less current will flow; if we increase its length, less current will flow. In both cases the resistance of the circuit has been increased. When a street-car rail gets very dusty, the motorman has to abuse his car to make his time, because the dust will not allow the current to pass freely; it offers resistance to the current and does not allow the car to get as much power as it would get were the rail clean, as it is in wet weather. If the car is in motion, it will run through very thick dust and the wheels will each drag an arc; but if at a standstill on a thoroughly dusty rail, the dust holds the circuit open and the car cannot start until the motorman applies one of his remedies for a *grounded rail.* As the car gets farther away from the power house, the lamps grow dimmer, showing that they are getting much less current; the car gets poor power too, and runs slowly; this is because a long feeder, a long trolley wire, and a long stretch of bonded rail have a great deal of resistance. Resistance in the right place is a good thing, but in the wrong place it gives no end of trouble.

**12.** Resistance is here spoken of as an actual thing, and as such, must exist in quantity. It is, therefore, measurable; but to measure it, we must have a unit in terms of which to express its value.

**13. Application of the Ohm.**—The refined definition of the value of the ohm is, in terms of the dimensions of a column of mercury, measured at a certain temperature; but to be more practical, 1,000 feet of No. 10 Brown & Sharpe (B. & S.) gauge copper wire measures about 1 ohm.

A five-lamp street-car circuit measures about 1,000 ohms; this makes one lamp measure 200 ohms. The rheostat used under a car equipped with series-parallel controllers, and a pair of 30-horsepower motors, is about 5 ohms, when cold, but warms up to 8 or 10 ohms, and often more, according to the abuse it gets. An arc lamp has a resistance of about 4 ohms in the arc when burning at the right candlepower. Heater circuits vary in resistance from 40 to 150 ohms, according to the notch used. The resistance of the human body varies very much, and seems to follow no certain law. The same person will measure differently on different days, the measurement ranging from 4,000 to 20,000 ohms. Some substances have more resistance than others; copper has more resistance than silver, and iron has about seven times as much resistance as copper; i. e., if 1,000 feet of No. 10 copper wire measures 1 ohm, 1,000 feet of No. 10 iron wire will measure 7 ohms. Those substances of comparatively little resistance—such as all the metals, carbon, salt water, etc.—are called *conductors*, because they conduct current, and are used for that purpose. Those substances through which current at ordinary pressures will not pass, are called *insulators;* air, mica, glass, porcelain, rubber, and oils are insulators. On a trolley line, the trolley wire, the rails, and those large black heavily insulated wires running parallel to the track, and called *feeders* because they feed power to the system, are all conductors; but the wooden poles, the hangers—those devices by means of which the trolley wire is hung from the cross-wires, called *span wires*—

and the *breakers*, so called because they break the trolley wire up into sections that have no electrical connection with each other, are all insulators. Among the conductors on a street car we find iron, steel, carbon, copper, brass, lead, and phosphor bronze. Among the insulators we find mica, rubber, porcelain, paper, asbestos, sealing wax, cotton, and numerous patented compounds, containing more or less of the above ingredients. Each particular insulation will be assigned its place and specific duty in a later Paper, where details are considered.

---

## OHM'S LAW.

**14. Variation of Current With Voltage.**—From what has preceded, it might easily be inferred—and correctly so—that voltage, current, and resistance are dependent on one another in some regular way. It is not proposed to introduce any mathematical ideas, not even those of arithmetic—arithmetic is probably the most difficult of the lower branches of mathematics—for they are not necessary to a clear understanding of the simple relations existing among the above members; viz., volts, amperes, and ohms. Ohm's law states, in substance, the following facts: *In an electrical circuit, the current varies directly as the electromotive force or volts, and inversely as the resistance or ohms.* Take the first part of the law; viz., *the current varies directly as the volts.* This means that the current does just as the volts do; whatever change takes place in the voltage takes place in the current, and in exactly the same measure. If the voltage is removed entirely, the current becomes nothing; if the voltage is doubled, the current is doubled; if the voltage is halved, so is the current. Take the following as practical examples: If a main-line fuse blows at the power house, or the main-circuit breaker goes out, the line gets no voltage; hence, there is no current, the lights go out, and the cars must come to a standstill and wait for the voltage to come on again. If the cars then start all at once, the flow of current

is so great that the breaker goes out again and there is more delay. A motorman can often save much time by using a little judgment in watching his lamps, and starting his car only when the lamps burn brightly. The faster a dynamo armature runs, the higher the voltage it will generate; consequently, when an engine runs away, as they sometimes do, the voltage gets very high, as also does the current, and the street-car lamps all burn out.

**15. Variation of Current With Resistance.**—Now for the second part of the law; viz., *the current varies inversely as the resistance.* This means that, whatever happens to the resistance, just the opposite change takes place in the current, and in the same measure. If the resistance of a circuit is doubled, the current is halved; if the resistance is trebled, the current becomes one-third as great; if the circuit opens and the resistance becomes infinite, the current becomes zero. For example, if a car fuse blows, or a loose motor connection gives way, or a motor brush breaks and falls down into the motor, the resistance becomes infinitely great, the current drops to zero, and the car is unable to move. On the other hand, if the resistance of the circuit is decreased, the current is increased in just the same measure; if the resistance is halved, the current is doubled; if the resistance becomes one-third as great, the current is trebled, etc.; and if, through some defect in insulation of a motor or of a controller, the current follows an unnatural path from the trolley side of the circuit to the rail, or, more generally speaking, from the positive to the negative side of any circuit, this path is apt to be of exceedingly low resistance, constituting what is called a **short circuit,** with the result that the current becomes very great and the car fuse blows. As a common, every-day example, when the current, through some abuse, probably, jumps from the brush holder or from a field lead to the motor frame, it finds a much easier path to the other side of the circuit, whence the current is said to take a *short* path, and the new circuit of which this path is part is called a *short circuit.* As a beginning to the

conclusion of this talk on Ohm's law, it might impress the above facts on the mind to say that voltage *causes* current, and resistance *stops* it as far as it can.

**16.** Always bear in mind that *voltage* is expressed in *volts*, *current* in *amperes*, and *resistance* in *ohms*.

## THE MAGNET.

### TYPES OF MAGNETS.

**17. The Horseshoe Magnet.**—Nearly every one knows something about the common horseshoe magnet, if nothing more than that it is generally painted red down to within a short distance of the ends, one of which is marked *N*, the other *S*; that it will pick up pieces of iron and steel, and will not pick up pieces of brass or wood; and that it has the general shape of a horseshoe. As all motor action is based on properties held by the horseshoe magnet, a little talk about it will be very useful.

**18.** Fig. 4 shows the general shape of such a magnet. Straightening a magnet out into a bar, such as that shown in Fig. 6, would not destroy the magnetism, provided the magnet were not heated, but would weaken it very much. Such a magnet as this is called a *bar* magnet. These magnets are known as *permanent* magnets, and they are made of hard steel, because hard steel has the property of holding for years most of the magnetism given to it; whereas soft steel and iron lose most of their magnetism as soon as the magnetizing force, whatever it may be, is taken away. If a piece of iron or steel is laid across the ends *N* and *S*

FIG. 4.

of a horseshoe magnet, it forms what is called a *keeper*, and some force is required to remove it. This force can be felt long before the keeper touches *N* and *S*. *N* and *S* are called the *poles* of a magnet, *N* being the north pole and *S* the south pole. These names come from the fact that any magnet free to turn will try to point one end towards the earth's north pole. On this fact depends the action of a ship's compass, the needle of which is nothing more than a bar magnet free to turn round a jeweled center. The poles of a magnet have this very peculiar property: the north pole of one magnet will attract the south pole of another magnet, but will repel its north pole, and vice versa; *like* poles repel each other and *unlike* poles attract each other. If a magnet, such as that shown in Fig. 4, is laid on a table and covered with a piece of paper, iron filings, sprinkled upon the paper at the same time that the paper is tapped with the finger to shake it a little, will be seen to arrange themselves in well defined lines, some straight and some curved, from one pole to the other, and these filings will flatly refuse to take up any other direction, until the magnet is disturbed or some other magnet or piece of magnetic metal is brought near enough to influence them. The paths along which the filings place themselves show the direction of action of the forces that try to pull *N* and *S* together, hence, these paths are called **lines of force.** Every magnet has at least two poles, and from these poles shoot out lines of force in paths that can be readily traced by means of iron filings. Fig. 5 shows the direction of a few of the lines of force from a horseshoe magnet as they would be indicated by iron filings.

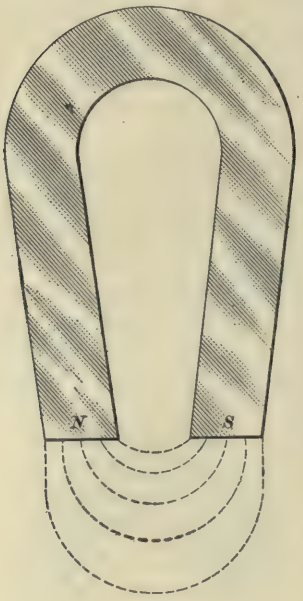



FIG. 5.

**19. Bar Magnet.**—Fig. 6 shows a plain bar magnet, with the direction of its lines of force, as indicated by the iron filings. The lines of force come out of the *N* pole, go around through the air, and reenter the magnet at the *S* pole. It must be noticed in both cases that the filings are not attracted to the center of the magnet; this is because at that point the lines are entirely within the magnet and are not felt outside of it; it is only where they pass into the air that their influence can be felt outside of the iron, and this is so because the air conducts lines of force so badly that they draw iron in to get a better path to travel through.

FIG. 6.

**20. Ring Magnet.**—Fig. 7 shows a ring magnet with a narrow gap in it at *a*. This magnet is a modification of the horseshoe type of Figs. 4 and 5, and approaches the general shape to be found on some electrical machines.

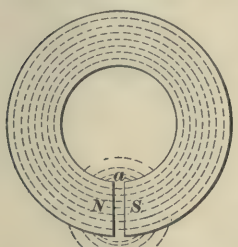


FIG. 7.

**21. Closed Magnetic Circuit.** Fig. 8 is the same as Fig. 7, except that there is no air gap. This sort of path for lines of force called *magnetic circuit* is not found on any of the machines with which we shall have to deal, but it shows very well what is meant by *closed magnetic circuit;* that is, the lines of force are everywhere within the iron itself, and do not enter the air. Such a magnet, therefore, would not affect outside pieces of iron.

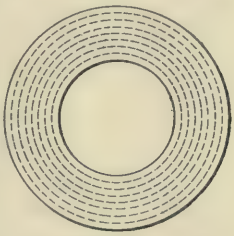


FIG. 8.

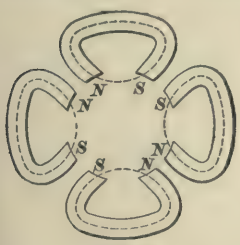


FIG. 9.

**22. Multiple Horseshoe Magnet.** Fig. 9 shows four horseshoe magnets so placed as to very nearly approach the magnetic circuit to be found on a

street-railway motor. A street-railway motor could be made with just such an arrangement of magnets, but the motor would be heavy for its power, because permanent magnets are not as strong for a given weight as are some magnets to be talked of later.

**23. Street-Car Motor Magnet.**—Fig. 10 shows a slight modification of Fig. 9, and is a nearer approach to Fig. 11,

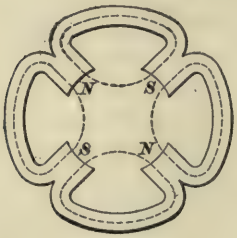



FIG. 10.

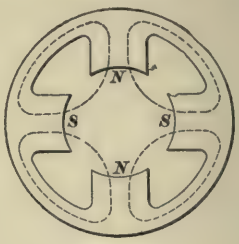



FIG. 11.

which is the magnetic-circuit diagram of an actual street-car motor. In these last two diagrams there are four magnetic circuits, as indicated by the dotted lines, which show the paths of the magnetic lines of force.

---

## THE ELECTROMAGNET.

**24. General Principles.**—If an electric current be passed through a wire, the wire will become surrounded by lines of force and act like a magnet. In Fig. 12, $B'$ is a battery, and $A$ $C$ is a wire through which $B'$ sends the current. As soon as the current passes through $A$ $C$, lines of force surround the wire and give to it the power of attracting pieces of iron and wires carrying current. If the trap doors in a motor car are lifted, and the motor leads closely watched, it will be observed that, when the motorman throws the current on, some of the motor leads swing in towards the motor, and, when he throws the

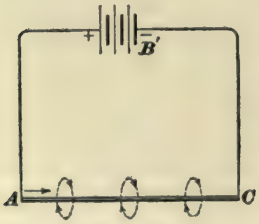



FIG. 12.

current off, these leads swing back to their normal positions. This is because the motor, with its lines of force, and the current-carrying motor leads with their lines of force, are all magnets and have the power of attracting one another.

**25.** In Figs. 13 and 14 there are two pairs of wires carrying currents, the direction of which, in each wire, is shown

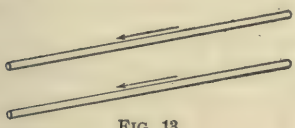


FIG. 13.

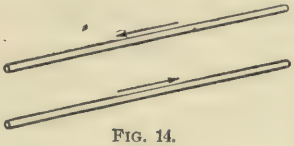


FIG. 14.

by the arrowheads. In Fig. 13, where the two currents flow in the same direction, the two wires will attract each other. In Fig. 14, where the two currents flow in opposite directions, the two wires repel each other and try to move apart. Where the currents used are small and there are but two wires, the effect is weak and may not be decided enough to see, unless special provision is made for giving the wires great ease of movement; but just step into a street-railway power house and watch the big compound leads hanging from the generator brushes, and no further testimony will be asked. There are at least two cases on record where the brush-holder lead was too long and the attraction of the armature was so great that it drew the lead in, rubbed its insulation off on the pole piece, and short-circuited the machine.

**26. The Spiral or Solenoid.**—The magnetic effect of a current in a wire can be made many times stronger if the wire be wound up into a spiral, as shown in Fig. 15. Such a spiral is called a *solenoid.* Such a solenoid, when carrying a current, has all the properties of a magnet, and is, in fact, what is called an **electromagnet.** It can attract other electromagnets carrying a current, and can draw into itself with great force rods of iron or steel held up to its end.

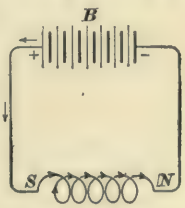



FIG. 15.

A test with the compass will show that the electromagnet

has a north pole and a south pole; further testing will show that the polarity of any given end depends on the direction in which the current flows around the electromagnet. If, as in Fig. 15, the current flows around in the direction of the hands of a watch, the left-hand end will be a south pole, and the right-hand end will be a north pole. If the current flows opposite to the direction of the hands of a watch, the polarity will be reversed. A great deal depends on the polarity of a spiral or a magnet. What has been said of the pole relation of permanent magnets is true of spiral or electromagnets. The *N* pole of one spiral will attract the *S* pole and repel the *N* pole of another spiral. The *S* pole of one will attract the *N* pole and repel the *S* pole of the other. In short, *like* poles repel and *unlike* poles attract each other. This fact is a very important one to us, because on it depends the almost indispensable feature whereby a street-car motor's direction of rotation can be reversed by reversing the polarity of one of its magnets. An explanation of this will be given later.

**27.** In Fig. 12 it will be seen that a wire carrying current is surrounded by a series of little circular lines of force. In Fig. 16 this is made plainer; here the wire carrying a current is supposed to pass straight down through the page on which we are reading, and the dotted circles show the series of concentric lines of force, the distance apart of which increases as the lines become more removed from the center of the wire. The number of these lines of force depends on how many turns of wire are in the spiral, and on how many amperes of current are flowing through these turns of wire. If the number of turns of wire or the number of amperes of current is doubled, the number of lines of force is doubled; if both the turns of wire and the amperes of current are doubled, the

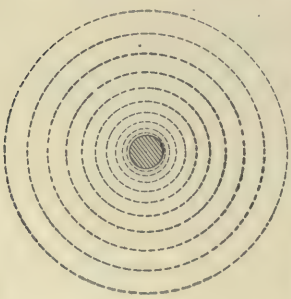


FIG. 16.

number of lines of force will be twice doubled and become, therefore, four times as great.

**28. The Core.**—The effect of the spiral as a magnet may be very much increased by putting inside of it a piece of soft iron, called a **core** (see Fig. 17). The soft-iron core offers much less resistance to the passage of the lines of force than the air does, so that not only are there more of them created, apparently, but also many of those little circular lines of force that formerly surrounded one turn of the spiral now become elongated and follow a course through the iron core from end to end, where very strong poles are developed and the strength of the magnet is very much increased. As we said above, the effect of putting in an iron core is to increase the number of lines of force many times, but, with the core once in, the effect of increasing the number of turns of wire in the spiral, or the number of amperes of current flowing through it, is not the same as it was with the spiral free from iron. Doubling the turns or the current will no longer double the number of lines of force, for this reason: the first few lines forced through the iron by means of a current flowing around a spiral, the iron accepts very freely; the next few lines do not find a place so readily, and when the magnetizing force is steadily increased a point is soon reached where the iron begins to be crowded, and a condition is finally obtained where increasing the magnetizing force a great many times increases the number of lines of force very little. At this point the iron is said to be saturated; it has all the lines of force that it can take, just as a rag is said to be saturated when it holds all the water it can. As a more apt illustration, suppose that it is desired to fill a headless barrel with motormen's switch irons; the first ones go in easily, but the last ones do not. The more irons there are in the barrel, after a certain limit is reached, the harder it is to get in any more; so with lines of force,

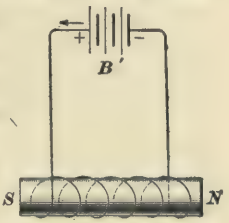


FIG. 17.

the more there are in a piece of iron the harder it is to force in any more.

**29. Comparisons Between Electromagnets and Permanent Magnets.**—Both permanent magnets and electromagnets, or spirals, have been considered and their properties found to be very much the same. They both have magnetic lines of force shooting out from them and forming what is called their *magnetic field.* For the same uses, both kinds of magnets have the same general shape; they both attract iron and other magnetic metals, and both refuse to pick up wood, brass, zinc, and such like. Their main difference is that one requires hard steel and the other requires soft iron; the reason of this has been given in Art. **18,** but to refresh the memory on such an important point, it may be repeated that, while soft iron can be temporarily magnetized to a much higher degree than hard steel, it loses this magnetism as soon as the cause of it is removed; hard steel holds its magnetism for years. As an every-day illustration, take the magneto in a telephone, or take the more interesting case of getting a watch charged. Many motormen have had this experience. If the watch is a cheap one, the chances are that the cheap grade of steel in it will soon lose its magnetism through the jolting of the car; but the fine steel in a good watch will retain its magnetism a long while, and it can be removed in only two ways. The more practical way we give: Suspend the watch by a double string about 2 feet long, twist up the string well and set the watch to spinning; while it is spinning bring it up to a dynamo gradually, and withdraw it before the watch stops spinning. Repeat this operation several times, set the watch, let it run for a day, and if it is still charged, give it another spin. The leather watch chains worn by motormen are no protection to a watch. It is not the electric current that gets into a watch and injures it; it is the stray magnetic lines of force from the motors or from the magnetic blow-out controllers. These lines of force (magnetism) will pass through everything that we know of, very nearly as well as they will pass

through air, so they cannot be insulated. They may, however, be coaxed into taking a by-path that is easier to follow than that leading through the object to be protected, and it is upon this principle that watch protectors are made. A watch protector is simply a soft-iron case that goes over the watch; it can be bought from any jeweler for about 15 cents. Any magnetism in the neighborhood of a watch protected by one of these cases will pass into the case and pass out of it again without touching the works of the watch. Soft iron is selected for electromagnet cores, because so much more magnetism (so many more lines of force) can be urged through it by a given number of amperes flowing around a given number of turns. Soft iron does not become saturated so soon as hard iron or steel does. This means, in effect, that if a certain amount of magnetism be required, a soft-iron core, to do the work, need not be as large as a steel one. This saves iron and copper also. Sometimes, however, the pieces of iron required in electrical work are too intricate to be forged, so a compromise is made by using a special low-carbon cast steel, very much stronger than cast iron, and magnetically almost as good as wrought iron. Such steel as this is found in all modern street-railway motors and in some dynamos.

## MOTORS.

### MOTOR ROTATION.

**30.** It is true of any magnet, whether permanent or not, that the *N* pole will repel the *N* pole of any other magnet and attract its *S* pole; it is also true that the polarity of an electromagnet depends upon the direction in which the current flows around its winding. In Fig. 18, *A* and *B* are two permanent bar magnets; *A* is fixed, but *B* is free to turn around center *o*. In the figure the *S* poles of *A* and *B* are

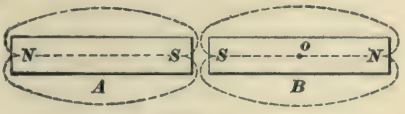



FIG. 18.

together, so that they are repelling each other, and $B$, if allowed to move, will swing around into the position indicated in Fig. 19 with the $N$ and $S$ poles together, in which position $B$ is perfectly satisfied to remain. Before $B$ settles down, however, it will oscillate in front of $A$. Suppose $B$ is restrained in the position of Fig. 18 by being held with the hand; as soon as it is released, $B$ will swing around in the direction of the hands of a clock with a force that gets stronger as $N$ approaches $S$, and it will not stop in the position $NS$, for its weight and speed will carry it on to position $N'S'$, Fig. 19, where the swing-by tendency is just balanced by back pull from unlike pole $S$ that $N$ has just passed. As soon as $B$ reaches the position $N'S'$, where the two opposing forces balance each other, it stops and swings back past $NS$ to dotted position $N''S''$, which is not quite as far out of center as $N'S'$. Then it swings back and forth several times, each successive swing being a little shorter in range than the one before it, till finally $B$ settles down into full-line position $NS$, where the direction of the lines of force of the two magnets is continuous and makes $A$ and $B$, in effect, one long bar magnet with an air gap in the middle. Now the object in view is to have $B$ rotate continuously and in a clockwise direction instead of oscillating in front of $A$; this can be done in two simple ways, both of which are easy to see. Suppose $B$ is released and allowed to start on its course as described above; now, just as $B$ gets to the position indicated by full line $ab$, let $A$ be removed altogether; the result will be that when $B$ swings around past $S$, there being no back pull, it goes on around past position $ab$, at which time, if magnet $A$ be restored to its former position, but with its poles reversed, $B$ will take a fresh start and keep on turning as long as we continue to remove $A$, reverse it end for end, and restore it to its place. In this demonstration we have assumed that $B$

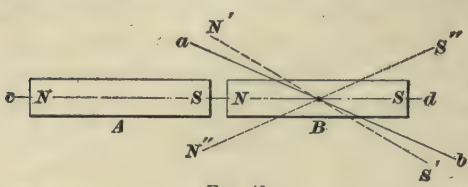


FIG. 19.

moves in a clockwise direction. As a matter of fact, the direction in which $B$ will start depends on which side of the horizontal line $c\,d$ the axis of $B$ rests, at the time $B$ is released; if $B$ inclines towards the position indicated by the dotted line $e\,f$, Fig. 20, its rotation will be clockwise; but if $B$ inclines towards the position indicated by the dotted line $g\,h$, its rotation will be counter clockwise.

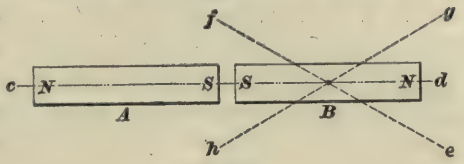


FIG. 20.

**31.** Another way in which $B$ can be made to keep on turning, and this way approaches more nearly the changes that take place in an actual street-car motor, is illustrated in Fig. 21. In Fig. 21, magnets $A$ and $B$ are both free to turn about centers. At the start the magnets are in the position of Figs. 18 and 20, with like poles together; let $B$ be released so that it turns clockwise, as shown by the arrow-head. When $B$, in its swing, gets to the position shown by the dotted line $a\,b$, its $N$ pole will have begun to feel very strongly the $S$ pole of $A$, and, if at this point, $A$ is slowly turned counter clockwise until the $B$ magnet almost reaches the position of Fig. 19, where unlike poles are together, then quickly turn $A$ magnet completely around, so that its poles stand end for end to what they are shown to be in Fig. 21, not only will $A$'s south pole drag $B$'s north pole around, but $A$'s north pole gets to its end-for-end position just in time to give $B$'s north pole an additional boost, due to repulsion. By some practice, a person can learn to rotate $A$ so well that $B$ is turned in either direction, according to its inclination at start, and even reversed in direction, by reversing $A$ at the right time.

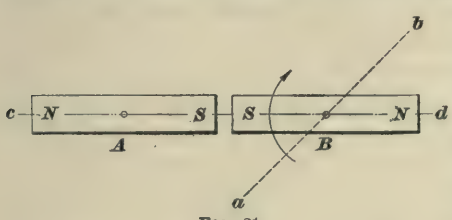


FIG. 21.

**32.** From the last demonstration it is easy to pass to one showing a method more like the actual method used to keep a motor armature turning in its field. In Arts. **30** and **31** a continuous rotation of magnet *B* depended on regularly and alternately and at the right time presenting to the poles of *B* the north and south poles of *A*. This was done in a mechanical way, and if the same thing can be shown to be done in a simple but entirely electrical way, one step nearer is made to the objects striven for, namely, a motor armature turning in a motor field, both armature and field being electromagnets.

---

### THE REVERSE SWITCH.

**33. Thomson-Houston Reverse Switch.**—Before this step can be safely taken, something must be known about the action of a reverse switch. In Arts. **26** and **30,** it was stated that the polarity of an electromagnet depends on the direction in which the current flows around it, and what an important bearing this has on motor action.

If, as in Fig. 22, the current flows clockwise, viewed from the left-hand of the magnet, the left-hand end will be the south end and the right-hand end will be the north end

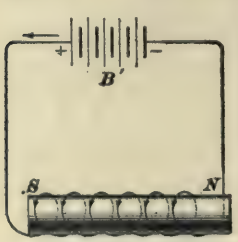


FIG. 22.

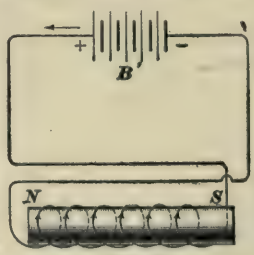


FIG. 23.

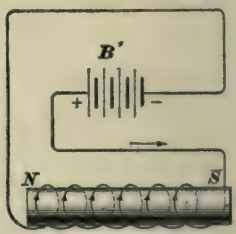


FIG. 24.

of the magnet. If, as in Figs. 23 and 24, the current flows oppositely, the polarity of the magnet will be reversed. It is easily seen then, that, with the proper devices for doing so, the polarity of the magnet can be rapidly reversed by reversing the direction of the current. Fig. 25 gives a diagram of the reverse switch to be found on all motor cars

equipped with the old Thomson-Houston street-car system, and its principle pure and simple is embodied in all reverse switches. In Fig. 25, $e_1$, $e_2$, $e_3$, $e_4$, $e_5$ are connecting posts to which wires can be attached, the two outside ones of the three in a row being connected together as shown by the dotted line $e_3$ $e_2$. $B'$ is the battery, as usual, and $A$ the magnet coil. When the reverse switch is in the full-line position of Fig. 25, the current from $B'$ follows the path $B'$–1–2–3–4–5–6–7–8–$B'$. It enters the left-hand end of the coil and flowing around it in a clockwise direction makes the left-hand end a south pole; when the switch blades are thrown over to the dotted position, the current leaves the battery from the same pole, of course, but following now the path $B'$–1–2–$e_3$–$e_2$–7–6–5–4–3–$e_1$–8–$B'$, it enters the coil at the right-hand end, flows around it clockwise and makes the right-hand end a south pole—just the opposite to what it was before the reverse switch was thrown.

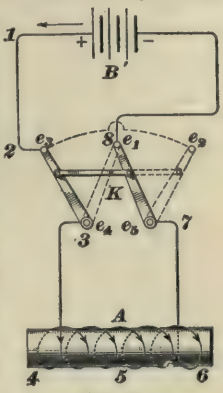


FIG. 25.

**34. Reversing the Poles of a Magnet.**—Having now a working knowledge of the object and action of a reverse switch, it will be well to apply it in a simple way to the reversal of the poles in magnet $A$. In Fig. 26, $B$ is a permanent magnet as before, free to turn on a center; $A$ is an electromagnet that gets its current from battery $B'$ through the reverse switch $K$, by means of which, the polarity of $A$ can be reversed at any time. With this arrangement, magnet $B$ will be self-starting

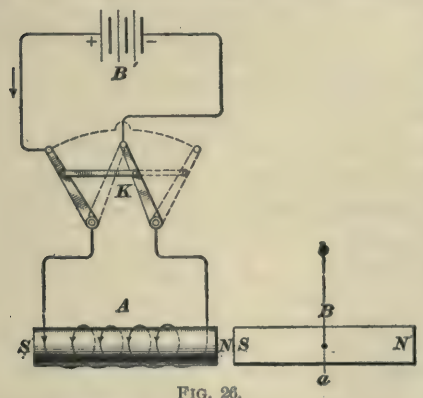


FIG. 26.

in every position. This would not be so were a piece of soft iron substituted for permanent magnet $B$, because then in position $a\ b$, exactly at right angles to the axis of magnet $A$, whatever may be its polarity, one end of $B$ will be attracted by $A$ and the other end of $B$ will be attracted by $A$ with exactly the same force, so that there will be no tendency for $B$ to turn. If, however, $B$ is a permanent magnet, it will have an independent polarity of its own, and in position $a\ b$ one of its poles will be attracted, and the other of its poles repelled by $A$, with the result that $B$ turns around its center. Suppose the relative polarities of the two magnets are given in Fig. 26. In this position, the two magnets have their unlike poles together; and, the position being a stable one, they are contented to rest that way. If, however, we wish to start $B$ rotating, all that is necessary is to throw over the reverse switch. This reverses the polarity of $A$, and puts two like poles together, and $B$ starts off in whichever direction it finds it the least effort to turn. Suppose $B$ turns in a clockwise direction; the right-hand end of $A$ is now a south pole and the north end of $B$ is swinging around towards it; the force of its swing will carry the north pole of $B$ beyond $S$, the point where it would like to stop, and, if at just the moment $N$ is in line with $S$, the reverse switch be thrown, the back pull between $S$ and $N$ will be removed and replaced by repulsion between $S$ and $N$, and $B$ will swing on around. By handling the reverse switch $K$ with judgment, smooth, continuous rotation of $B$ can be obtained, and this rotation can be stopped and even reversed by introducing the back pull at the right time. With this arrangement we have passing through the spiral of magnet $A$ what is called an alternating current, because it goes first one way and then the other, and the lines of force due to it also run first one way and then the other, making alternately north and south poles.

### THE COMMUTATOR.

**35. Simple Commutator.**—The arrangement described in Art. **34** is a very good one to illustrate principles, and it brings to light several things well worth knowing, but its

main objection is one that bars it from being called an exact reproduction of the action that takes place between the two electromagnets (the armature and the field) of an actual street-car motor. This objection is, that manual labor, namely, the throwing of the reverse switch, must be done in order to keep up the rotation. On an actual motor the reverse switch, called a commutator, is on the moving part, called the armature, and by means of the commutator, the current from the battery is reversed through the armature coils (the spiral) twice in every revolution; this reversal of the current keeps the armature core of such polarity in relation to the field that the core is never satisfied with its own position, and keeps shifting so as to cause rotation. Fig. 27 shows the simplest form of commutator that can be made; it consists of two semi-cylindrical pieces of copper *c*, *c'* fastened to a wooden drum. The two ends of the spiral are attached to these two **commutator segments,** or **bars,** as they are more commonly called, and the bars and spiral rotate with the core not shown in this figure; *b* and *b'* are springs that stand still and sweep the commutator as it goes around, in this manner giving to the commutator, and to the spiral attached, the current from battery *B'*. From the fact that the springs *b* and *b'* sweep the commutator they are called **brushes.** As the brushes stand still, and as the same one is always connected to the positive side of the battery, the result is that first one end of the spiral and then the other end is attached to the positive side of the battery, so that twice in every revolution the current in the spiral is reversed in direction. For reasons that will be explained later this commutator has to be slightly changed to make it work on the simple motor that we have selected to talk about. The

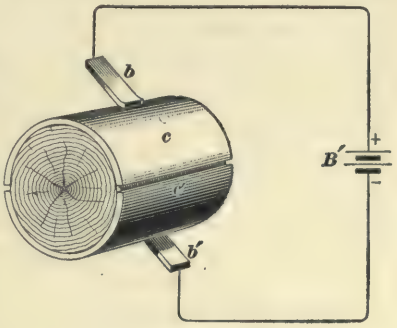


FIG. 27.

change is simply in the shortening of the arc covered by the bar, so that during part of each revolution the battery is idle and gives this peculiar form of core a chance to get rid of the back pull exerted by *A*. In the position shown in Fig. 28, the positive brush *b* is in contact with the upper bar *c*,

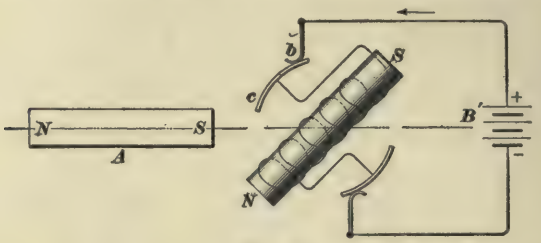



FIG. 28.

and the polarity of the core is such that the north pole of the armature is being drawn towards the south pole of the field. If the brushes and bars were allowed to make contact after *N* swings past *S*, there would be a very strong back pull—enough to stop the rotation. To avoid this, the bars are made narrow and are set so that contact is broken just at the time, or a little after, *N* and *S* are exactly opposite. *N* swings on around and contact is not made again until the armature reaches a vertical position, when the same cycle of operation is repeated.

**36. Excited Field.**—Since the field is furnished by a permanent magnet, and since the armature core is soft iron,

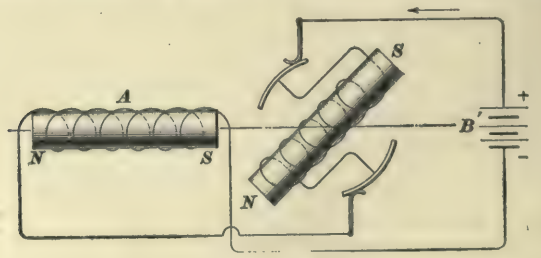



FIG. 29.

the field magnet will always have an attraction for the armature core whether its winding carries a current or not, so

that there will always be a back pull on $N$ after it has passed $S$. If, as in Fig. 29, we make the field magnet also an electromagnet supplied from the battery $B'$, the little motor then has an electromagnet for supplying the field and whenever the current ceases to flow in the armature coils it also ceases to flow in the field coil and back pull is done away with.

---

### MOTOR CONNECTIONS.

**37.** Before taking up a figure showing the connections of an actual street-car motor, it will be well to sum up a few of the facts stated in what has gone before or to be inferred from it. To make a motor that will run, there must be provided two magnets; one to stand still, and the other to be free to turn about a center. The one that stands still sends out its magnetic lines of force and provides what is called the magnetic field; the magnet that is free to turn has magnetic lines of force of its own, and these being acted upon by the lines of force of the magnetic field, the movable magnet, called the armature, must turn. Every motor, then, must have a magnetic field and an armature. Fig. 30 shows the connections of an actual motor. $F$ is a winding on the soft-iron or soft-steel frame $T$, and this winding is called the field winding, because it provides the field lines of force, or field magnetism. $b$, $b'$ are the brushes and $c$, $c'$ the commutator bars; $B'$ is the battery to supply the current for running the motor. This figure is not drawn to scale, and the motor shown is selected merely to illustrate principles that have been talked of in the preceding pages. In a commercial form of motor the principles are the same, but they are carried out in a way less easy to understand until more of the details of the subject have been mastered, so, as this lesson is devoted entirely to principles upon which motor action is based, any talk about

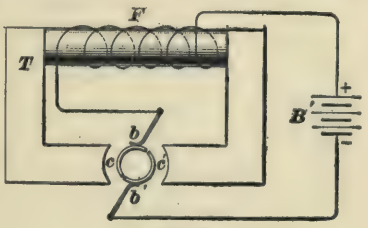



FIG. 30.

complications that arise from the carrying out of details would be out of place here and is therefore deferred to a later Paper.

**38.** If the gradual development of the motor principle has been carefully followed from Art. **30,** the student should be able to answer the question, What causes a motor armature to turn when a current is sent through a motor? The very simple, but progressive, answer is this, Unlike poles of two neighboring magnets attract each other and if one of the magnets is free to move, it does so. In a motor there are two iron cores: a field core and an armature core. The field core stands still, but the armature core is free to move when it is called upon to do so. The effect of sending a current through the wire wound on the cores is to make both of them magnets. The field magnet attracts the armature magnet and the armature moves. The mechanical devices are such that the armature does not move sideways or any other useless way, but it turns in its own bearings, and, being geared to the car axle, the wheels move also.

**39.** About all has been said that can be said about motor action proper, or the cause of rotation, without going deeper into the subject than this paper calls for, and without having before us a correct mental picture of an actual motor and its workings with all its details brought out plainly. As it is the intention, in another Paper, to present the motor in its many and complicated relations to the devices that it controls, and to those that control it, it will be better to defer these matters until then, when phenomena and their causes and effects can be worked in together to greater advantage.

---

## HEATING OF MOTORS.

**40.** The ordinary street-car heater is a plain proof that if a large enough current is sent through a wire, the wire will get hot, and the large pile of roasted cotton-covered magnet wire to be found around almost any street-railway

repair shop is very expensive but impressive evidence that motors sometimes get too hot. They do get too hot, and the reason they do so is that they get more current than they are able to stand. This may be due to the fact that the motors have grown too small for some additional work put upon them, or they may be receiving abuse in handling, or they may be of poor design. In any case, the cause of the heat is the current, and any increase in the value of the current sent through a motor causes a larger than proportional increase in the heating. If the current is doubled, the heat caused becomes four times as great. If the current is trebled, the heat becomes nine times as great, and so on; so it is evident that the motorman can do a great deal towards keeping down the temperature of his motors by handling his controller with judgment and allowing his car to coast whenever it is possible.

# MOTOR PRINCIPLES.

(PART 2.)

## MOTORS AND DYNAMOS.

### COUNTER ELECTROMOTIVE FORCE.

**1. Meaning of C. E. M. F.**—Counter electromotive force, generally written C. E. M. F., is one of the indispensable properties of a motor; and to get a good understanding of its meaning and action, it is necessary to know a little of what goes on in the armature of a dynamo; for C. E. M. F. is nothing more or less than the dynamo property of a motor. C. E. M. F. might correctly be called any of several other names, all of which will be seen to convey the right idea, after we know more about that idea; the other names are: *motor electromotive force*, *back electromotive force*, *back voltage*.

**2. Generation of E. M. F.**—When a wire passes through a magnetic field in such a way as to cut the lines of force, there is a voltage set up in the wire, and if the two ends of the wire are held together, so as to form a closed circuit, a current will flow in the wire. One favorite way of testing this statement is to take an ordinary horseshoe magnet, remove its keeper, and wave a wire up and down between



For notice of the copyright, see page immediately following the title page.

the poles at right angles to the plane of the magnet. The wire must be part of a circuit including a delicate instrument called a *galvanometer*, which has a needle similar to that in a compass, except that it is much finer and much more delicately suspended. The galvanometer is very sensitive to the least flow of current, and on moving the wire *A B* between the poles of the magnet *M*, Fig. 1, the movement of the needle can be easily seen. On moving the wire up, the needle throws one way, and on moving the wire down, the needle throws the opposite way, showing that the polarity of the voltage set up in the wire depends on the direction in which the lines of force are cut. This test is good enough proof of the presence of current in the wire, but the following is more practical, more striking, and has less mystery attached to it. Take a wooden drum, shaped something like an ordinary rolling pin, and wind on it, as shown in Fig. 2, one turn of No. 12 Brown & Sharpe (B. & S.) gauge, cotton-covered copper wire, soldering the ends of the wire together and securing it to the drum by means of double-pointed tacks. Make a center in both ends of the drum, so that it can be put in a speed lathe. Take a piece of steel, 18 in. $\times 1\frac{1}{2}$ in. $\times \frac{3}{8}$ in., and after bending it into the shape of a horseshoe magnet, with an opening large enough to let in the drum, as shown in Fig. 2, get it hardened by a blacksmith or toolmaker, and proceed as follows to magnetize it. Wind on it, by hand, as many turns as possible of

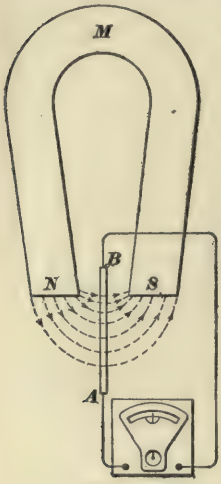


FIG. 1.

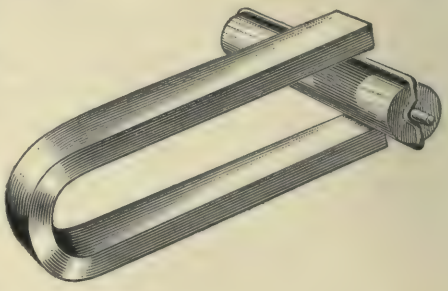


FIG. 2.

any sort of insulated wire that can be procured; after the wire is on, send through it as much current as safe heating will permit, and leave this current on for several minutes; after all this has been done, the piece of steel should be a very fair permanent magnet of the horseshoe type; next, put the drum between the centers of the speed lathe, secure it with a dog, and start up the lathe. While the drum is turning, slip the magnet around it, as in Fig. 2, and before very long the wire will begin to get warm, showing that a current is flowing through it. This arrangement is no less than a veritable dynamo; the horseshoe magnet furnishes the magnetic field, while the wooden drum is the armature. The lathe takes the place of an engine or other motive power. The main difference in principle between this arrangement and an actual dynamo lies in the fact that, here, all the current generated is wasted by flowing around in the wire and heating it, whereas, in a dynamo, it is collected and put to use.

**3. Distinction Between Dynamos and Motors.** From the previous statements made in regard to motors and dynamos, it is, no doubt, hard to see what is the difference between them. The fact is that, except in special cases, there is no difference at all, save in the nature of the work the two machines are called on to do. Any machine built to run as a dynamo, can, under the proper conditions, be made to run as a motor, and vice versa. A motor must be supplied with a current from a battery or a dynamo, and it is called on to do the mechanical work of turning a shop's shafting or running a car. A dynamo is run by an engine or a waterwheel, and is required to furnish the electric current for lighting lamps or running motors. The motor is supplied with electrical energy, and gives out mechanical energy. The dynamo is supplied with the mechanical energy of the engine, and gives out electrical energy.

**4. Analogy.**—From what has gone before, it can be stated as a fact that, when a current is sent through a wire properly disposed in a magnetic field, the wire, if free to move, will do so; also, that, when a wire forming part of a

closed circuit is moved in a magnetic field, in such a way as to cut the lines of force, the wire will have a current generated in it. This current is, in the first place, due to a voltage set up in the wire by its cutting the lines of force, and this voltage exists whether or not the conditions are such that a current can flow. In other words, any electrical circuit may have its full line pressure ready to act, although entire absence of current shows this pressure to be inactive. For instance, on a street-car system having only two cars, both cars might be running down hill and neither taking any current, but the voltage would still be there. This condition finds its exact analogy in a water-works system. The pressure on a pipe line is, up to a certain limit of load, kept the same all the time, and it does not make any difference whether the consumers are using any water or not, as there will still be pressure on the line. Flow or no flow, the pressure exists.

**5. Effect of C. E. M. F. on Motor Current.** — The resistance of a motor armature is very low—a fraction of an ohm—and were an armature laid on the floor, and full line pressure applied directly to it, without the flow of current being held back by some extra resistance being placed in circuit, the armature and everything else in the immediate neighborhood, the electrician not excepted, would be badly burned, unless some fuse or circuit-breaker acted very promptly to relieve the situation. Yet, when a car is running under full headway, each motor has 500 volts or more across its terminals, and the armature does not burn out. Why is it, then, that a motor can stand 500 volts across its terminals when all other resistance is cut out and the armature is turned at a high rate of speed, but is burned out if this same voltage is applied while the armature is standing still? When a car is at full speed, it means that the controller handle rests on a notch where all of the rheostat is out of use, and, up to the present, nothing has been said about anything to take the place of the rheostat, in holding down to a safe limit the value of the current. This is where the counter electromotive force plays an important part.

When the controller is put on the first notch, the car, if in good working condition and if the voltage is good, will start in an easy manner; it does not start with a jerk because the resistance in the rheostat, or starting coil, holds the current down to its proper starting value. If the car does start with a jump, it goes to show that some device is out of order. As soon as the current is turned on, the armature begins to revolve, and with it, as a matter of course, the wires wound on its core. The instant these wires move, they begin to cut the lines of force of the magnetic field, provided by the current in the coils on the field cores, and like any other wires moving across the lines of force of a magnetic field, they have an electrical pressure generated in them. This pressure acts in a direction opposed to that of the line voltage that causes the armature to turn; it bucks the line voltage, and tries to send a current back against that urged on by the line voltage. It can never do this, because it is due to the line voltage, and can, therefore, never equal or exceed it; but the counter electromotive force puts up a good fight and does not let the line voltage send as much current through the motor as it would send if the counter electromotive force did not exist. From the fact that its action is against, or counter, to that of the line electromotive force, this motor electromotive force is called the *counter electromotive force* of the motor. The counter electromotive force is, of course, zero when the car stands still, because its existence is due to the motion of the car; its value increases as the speed of the car increases, and is greatest when the car speed is a maximum.

---

### OHMIC AND SPURIOUS RESISTANCE.

**6.** As soon as a car begins to move, the resistance in circuit is of two kinds: the starting-coil, or rheostat, resistance, called *ohmic* resistance, because it is expressed in ohms; and the effective resistance, due to the opposition of the counter electromotive force. This latter is sometimes called *spurious* resistance (though the term is not a very good one) because the counter E. M. F. acts like resistance so far as holding back

the current is concerned. It acts like ohmic resistance and serves the same ends, but it is not ohmic resistance. Take a piece of wire, and it will have a certain *ohmic* resistance, whose value depends on the length, size, and substance of the wire; and this *ohmic* resistance will remain the same as long as the wire remains the same, because it is one of the inherent properties of the wire. But *spurious* resistance is not a property at all of the wire itself; it is due to the electric current in the wire and to the motion of the wire, and, as we shall see later, depends on the number of coils into which the wire may happen to be wound. If the wire is straight, it has very little spurious resistance, but if it is wound up into a spiral, or if it is given a high rate of motion across lines of force, the value of the spurious resistance increases a great deal, while the value of the ohmic resistance remains the same.

---

### SPEED AND C. E. M. F.

**7.** If the controller handle is allowed to rest a while on the first notch, the car will acquire a fairly good rate of speed on this notch. Now, take notice, the ohmic resistance of the circuit has not been changed; but, since the speed of the car has increased, and since the C. E. M. F. and spurious resistance are dependent on the car speed, they must have increased; therefore, the total resistance in circuit after the car starts is greater than it is before the car starts and the current is less; hence, the conclusion can be drawn that it takes more power to start a car than it does to keep one going after it is once in motion. This ought to be easy to see, because almost all of us are familiar with the fact that two horses have to pull harder to start a loaded wagon than they do to keep it going after it is once started. When the controller handle is advanced to the second notch, a part of the ohmic resistance in the starting coil is cut out, the speed of the car increases, and so does the C. E. M. F., to take the place, in a measure, of the resistance cut out of the starting coil. The C. E. M. F. does not necessarily increase an amount exactly equal to the resistance cut out of the coil, as can be

seen from the fact that when the controller handle rests on the fourth notch, and the spurious resistance of the C. E. M. F. is practically the only resistance in the circuit, the current is less than it was at the start, which goes to prove that, although the car is in motion, the total resistance of the circuit is greater than it was before any of the starting coil was cut out. On the third notch more ohmic resistance is cut out, and the C. E. M. F. increased by the increase in the speed; on the fourth notch, as stated above, all of the starting coil is cut out, leaving no ohmic resistance in circuit except the very low resistance of the motors. Hence, one can readily see the great importance of allowing the controller handle to rest a little while on each notch, to give the C. E. M. F. a chance to work up, replace the ohmic resistance cut out of circuit, and prevent an abnormal flow of current, when passing to the next notch. As the C. E. M. F. increases, the current decreases.

---

### THE LOOP AND THE SHUNT.

**8. Explanation of Shunt.**—Since the C. E. M. F. in a motor is due to the armature wires cutting the lines of force of the magnetic field, furnished by the current flowing in the field winding, the more lines of force there are for the wires to cut, the higher will be the C. E. M. F. at a given speed; and the fewer the number of lines of force there are for the armature wires to cut, the lower will be the C. E. M. F. generated at a given speed. Again, the C. E. M. F. fights against the line voltage and regulates the amount of current this line voltage sends through the motor; the higher the C. E. M. F., the less current can the line voltage force through the motor; and the lower the C. E. M. F., the more current can the line voltage send through the motor. The greater the current forced through a motor armature, the greater will be its speed, provided the field current is not increased in proportion at the same time. We can see, then, that if the C. E. M. F. of a motor is decreased, it will let a large current into the armature and increase its speed. To

decrease the C. E. M. F. of the motor, it is only necessary to decrease the number of lines of force that the armature can cut. This can be done in two ways: (1) by decreasing the number of active turns of wire on the field winding, or (2) by making part of the current that passes through the motor take another path and not pass through the field winding. The first method, known as the *loop* method, takes some of the turns away from the field; the second method, known as the *shunt* method, takes away some of the amperes. The name "shunt" is an English railroad expression, and when they speak of shunting a train, they mean to convey the same idea as we do, when we speak of switching or side-tracking a train. A shunt is a side track. In Fig. 3, the

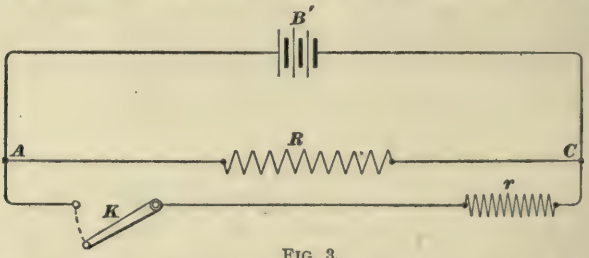



FIG. 3.

battery $B'$ sends all its current through resistance $R$, if switch $K$ is opened; but if $K$ is closed, the current, on getting to $A$, splits—part of it going through $R$, and part through $r$—the two currents uniting again at $C$, to return to the battery $B'$. In this case $r$ is the shunt or by-path.

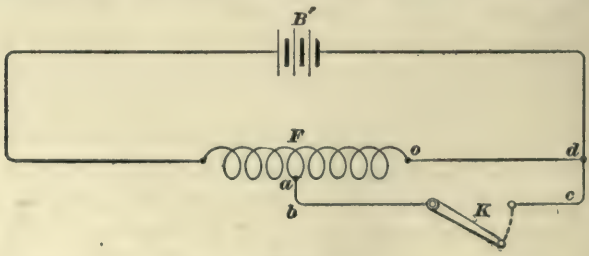



FIG. 4.

**9. Explanation of Loop.** — In Fig. 4, $F$ is the field winding of a motor, and the battery $B'$ sends its current

through all of the turns of wire in $F$, if the switch $K$ is open; but if $K$ is closed, part of the field ($a\ o$) is short-circuited, and the current, on getting to $a$, leaves the field winding and takes path $a$–$b$–$c$–$d$, which is of much lower resistance.

**10. Motor Field With Shunt.**—In Fig. 5, $F$ is a motor field winding, and $R$ is a shunt. If $K$ is closed, the current splits at $a$, part going through $F$ and part going through $R$. The amount of current that will go through each depends

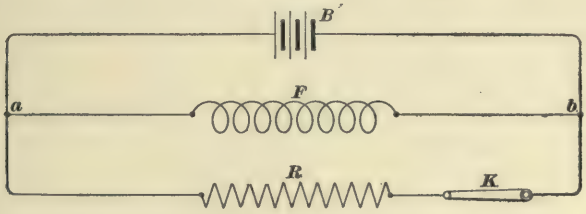



FIG. 5.

on the relative resistances of the field and shunt. If $F$ and $R$ have the same resistance, the same amount will go through each; if $F$ has twice as much resistance as $R$, $R$ will get twice as much current as $F$ does, because the current finds it twice as easy to go through $R$ as through $F$.

## HANDLING MOTORS.

### THROWING OFF THE POWER.

**11.** Any one that has run a car any length of time has noticed that if the power is thrown on and off again, before the car has a chance to move, the flashing in the controller is much worse than it is when the car is allowed to get in motion before throwing off the power. The reason for this is that if the current is put on and off without giving the car a chance to move, there is no C. E. M. F. generated to

resist the flow of current, and the only resistance in circuit is that of the starting coil; this being very low, a large current flows and causes a flash, which not only makes charcoal of the controller insulation, but is apt to hurt the insulation of the motors, by means of an effect to be considered later. Most of the damage done to motors and controllers, through throwing the current on and off without giving the car a chance to move, is not done by the motormen on the road; it is done in the house, at night, when the cars are all in, by the car washers and other help that know very little about running a car. As a rule, each car is run over a pit to be inspected, and is then shifted elsewhere to be cleaned and washed; this gives the starting coil a chance to cool off, and its resistance gets very low; the car is then shifted to its standing place for the night. This, as a rule, means that some man, with more confidence than horse sense, sets up the brake on the car, puts on the power, runs up to within 5 feet of the next car on the same track, throws off the power, puts it on again and runs the car up a foot or two more, then throws the power off again; and he keeps on jerking up 6 inches at a time until the two bumpers touch, instead of giving the car one good "kick" and doing the rest of the job with the brake, as every good man does. Very often, after a car has gone through this experience, it is more in need of inspection than it was when it came into the house. There are a great many car houses in the country where there is about ten times more shifting of cars done at night than there ought to be, and this weakness is the occasion of great increase in several items of expense. Among these are: time required to shift by men that should be doing something else; cost of the power used in shifting; abuse to equipment through poor handling; and last, but not often least, claims against the company for injuries done to the limbs of one man, through the ignorance or neglect of another. A car house should be built so that a car, on running in for the night, can be placed in its final resting place by a man that knows enough about his business to have some justifiable pride in his work.

### THROWING FROM SERIES TO PARALLEL.

**12. Motors in Series.**—The insulation on a motor or controller sometimes breaks down while the car is in motion, and when it does, it is generally while the controller handle is being advanced from the series position to the parallel position. Before this change can be intelligently talked about, it is necessary to know something about the difference between the series position and the parallel position. Two motors are said to be in *series*, when the current has to go through one motor in order to reach the other motor; that is, the same current goes through both motors. In Fig. 6, $A$ is the armature of one motor, and $F$ is its field winding; $A'$ is the armature of the other motor, and $F'$ is its field winding; $T$ is the trolley wire, and $G$ is the ground, or rail. It can be seen in the figure that a current cannot pass through one motor without passing through the other, and that the same current must pass through both. If the circuit is opened anywhere between $T$ and $G$, no current can get through either motor. An open circuit in either motor, then, stops the flow of current in both; for this reason, the paths through the two motors are said to be *interdependent*.

FIG. 6.

When two motors are connected in series, the *voltage* divides between them. In Fig. 7, $A$ is the armature of a 500-volt street-railway generator, supplying current to the two motors, $a$, $a'$, connected in series. If a test is made with a voltmeter, there will be found to be 250-volts drop across each motor. Any departure from this rule will be due to want of balance in the motors.

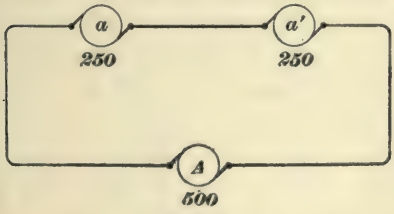


FIG. 7.

**13. Motors in Parallel.**—Two motors are said to be in *parallel*, or *multiple*, when they are so connected that the

current does not have to pass through either one to get to the other, but can go through one at a time or can go through both at the same time. In Fig. 8, $T$ is the trolley wire and $G$ is the rail; $F$ and $A$ are the field and the armature of one motor, and $F'$ and $A'$ are the field and the armature of the other motor. If switches $K$ and $K'$ are both closed, the current from the trolley wire, when it gets to $a$, splits, part of it going through one motor and part of it through the other. If the two motors are electrically balanced, i. e., if their ohmic resistances and the C. E. M. F.'s are the same, the two motors will each get the same *amount* of current, but will not get the *same* current as they do when they are in series. Each motor gets one-half of the total current taken from the trolley wire, whereas, in series, each one got all the current taken from the trolley wire. If switch $K$ is open, motor $F'A'$ can still get current. If switch $K'$ is open, motor $FA$ can still get current, as shown by the arrowheads in Fig. 8. From the fact that one circuit can get a current whether the other does or not, the two circuits are said to be *independent*. As an every-day example, take the case of a street car wired with two light-circuits: pull out a lamp anywhere in the car, and it will put out all the lamps on that circuit, because all the lamps are in series, as shown in Fig. 9, where $T$ and $G$ are the trolley wire and the rail, and $L$, $L$, $L$, $L$, $L$ are the five lamps in series. Where there are two or more circuits in parallel, pulling out one or all of the lamps on one circuit does not have any effect on the lamps in the

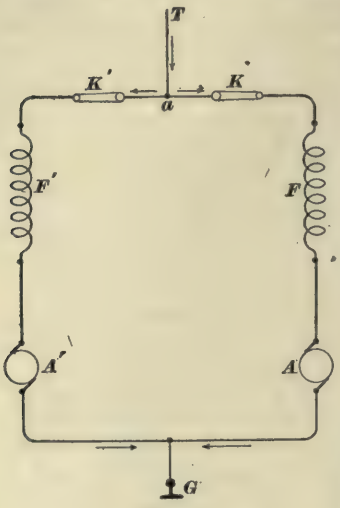


FIG. 8.

FIG. 9.

other circuits, because the circuits are in multiple (see Fig. 10) and are therefore independent of one another. The two circuits on a car considered together are wired in multiple series, because two groups of five lamps in series are connected in multiple. On some long cars there are three light-circuits in multiple, in which case they are connected as shown in Fig. 10. A very good way to remember the difference between series and multiple connection is this: when one speaks of a series of numbers, as 1, 2, 3, 4, 5 . . . . etc., he means numbers that come one after the other; so with lamps or motors or any other electrical devices connected in series; they come one after the other in the circuit, and the current must pass through them one after the other: now, the meaning of "multiple" is "many," or, in this particular case, "more than one," and "multiple circuit" means "more than one circuit." All the arc lamps in a small town are on one circuit, and are in series. All of the motor cars on any system are in multiple.

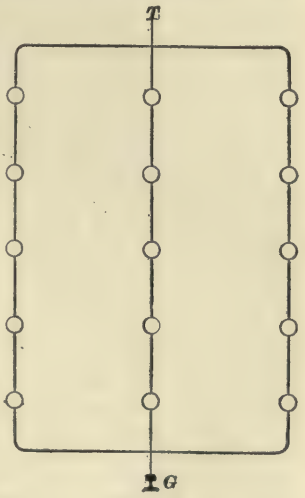


FIG. 10.

When motors are operated in parallel, the *current* divides between them. Fig. 11 shows two motors *a*, *a'* operated in parallel from the 500-volt generator *A*. It is easily seen that, in this case, part of the current will flow through *a* and part through *a'*. Ammeters placed in circuit with *a* and *a'* will each show the same current if the motors are properly balanced, and this current will be equal to one-half of the current flowing in armature *A*.

FIG. 11.

**14. Resistances in Series and Parallel.**—The reader should have a very fair idea, now, of the difference between series and multiple, or parallel, and should be in a position to grasp the idea of resistances so connected. Say that a certain piece of wire $A\ C$, shown in Fig. 12, measures 1 ohm; if a piece exactly like this is stuck on to its end, or, what is the same thing, if a piece of the same kind and size of wire, but of twice the length, is taken, its ohmic resistance will be twice as great, because a current passing through it would have twice as long a path to travel. If, instead of a piece twice as long as that in Fig. 12, a piece of the same length, but of twice the weight, is taken, its resistance will be but one-half as great, because the current would have twice as big a path to go through. Again, instead of one wire of twice the cross-section of that in Fig. 12, take two wires of the same kind $A\ C$ and $A'\ C'$ and connect them in multiple as in Fig. 13. These two wires in multiple have half the resistance of one wire alone, because there are two paths instead of one. Therefore, since two wires in series have twice the resistance of one wire alone, and since one wire alone has twice the resistance of two in multiple, two wires in series must have four times the resistance of two wires in multiple. Two wires in multiple will, then, allow four times as much current to flow as will two wires in series, for the resistance is but one-quarter as great.

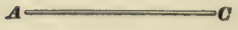


FIG. 12.

FIG. 13.

**15. Resistance Offered by C. E. M. F.**—Now, the resistance due to the opposition of the C. E. M. F. can be expressed in ohms, and in this case follows the same general laws governing ohmic resistance. On that controller notch where the motors are in series, and the C. E. M. F.'s of the two motors are the only resistances in circuit, the two C. E. M. F.'s are in series, and they hold the current down to a certain value; on that notch where the motors are in multiple, and all of the rheostat is cut out, the C. E. M. F.'s are in multiple also,

and, as such, offer much less opposition to the flow of the current than they do when they are in series.

**16. Lessening the Shock from Series to Parallel.** It is easy to see, then, what a violent change the car and its equipment would be subjected to, in going from series to parallel, or, as the motormen put it, in *throwing her over*, were not some means taken to make the change a gradual one. When the motors are in series, each motor gets the whole current, and this current has a value that depends very much on whether the car has been allowed to acquire a speed corresponding to the position of the controller handle. When the motors are in multiple, each motor gets but one-half of the whole current; but if the whole current is four times as much as it was on the last series-notch—and careless handling of the controller can easily make the current value exceed this—each motor gets twice as much current as it ought to, and continuous abuse of this kind will roast the fields of the best designed motor ever built.

Fig. 14 will give an idea of the means taken to lessen the violence of the change from series to parallel. *T* and *G* are

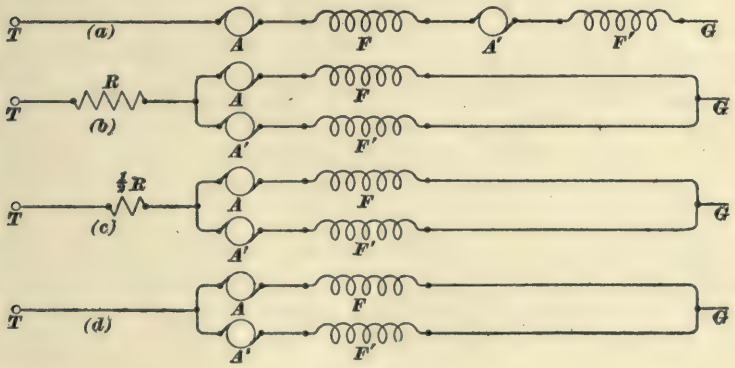



FIG. 14.

the trolley and the rail; *A* and *F* are the armature and the field of one motor, *A'* and *F'* the armature and the field of the other motor, throughout the series of diagrams. (*a*) represents

the connections on the last series-notch on any controller that does not use a shunt or a loop. The current from the trolley passes through $A$ armature, $F$ field, $A'$ armature, $F'$ field, one after the other, in the order named, and to the rail, not shown, at $G$. In this series of connections, the circuit opens entirely after leaving the position ($a$); that is, there is a place between the notches ($a$) and ($b$) where neither motor gets any current, and where, consequently, the car would stop, were the controller handle left on that position. When the position ($b$) is reached, the two motors are in multiple, but have a resistance $R$ ahead of them, so that the course of the current from $T$ to $G$ is by way of two paths: $T$–$R$–$A$–$F$–$G$ and $T$–$R$–$A'$–$F'$–$G$. In diagram ($c$) one-half of resistance $R$ is cut out and diagram ($d$) shows all of resistance $R$ cut out, and the motors in full multiple right across the line. The above combinations are not the ones best suited to cushioning the effect between series and parallel, because both of the motors are dropped out of the circuit at the same time, and both of the motors are picked up again in parallel at the same time, with the result that, on grades and with a heavy load, the car is apt to show the dropping of both motors by halting. On better combinations, but ones a great deal more difficult to follow, the motors are dropped out of circuit one at a time, if both are dropped, and are picked up again one at a time; on other combinations, one of the motors remains in circuit all the time, and one is dropped out only long enough to connect it in parallel instead of in series, when it is again picked up on resistance which is gradually cut out as the controller handle is advanced. From the above words, the reader must not get the very wrong impression held by so many motormen, inspectors, and even superintendents, that there are several notches on a controller, where the car is working on one motor only. There is a position on some controllers where this is a fact, but this position is in between two notches, and on a controller the index spring of which is in good order, it will be a matter of some trial to get the controller handle to rest there.

**17. Dropping and Picking Up One Motor.**—Fig. 14 (*a*) shows the last series-notch on a controller. Fig. 15 (*a*) and (*b*) shows the changes made in dropping one motor from the circuit and picking it up again with a resistance in ahead of it;

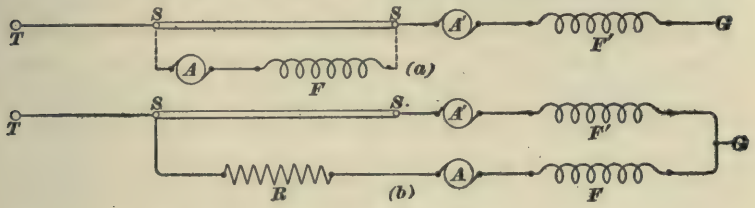



FIG. 15.

(*a*) shows one motor dropped out of the circuit entirely and its place occupied by a short-circuiting strip *S S*; (*b*) shows the motor in circuit again, but in multiple this time, and with a resistance *R* in ahead of it. As the controller handle advances on around, this resistance is cut out, and Fig. 15 (*b*) becomes the same as Fig. 14 (*d*).

**18. Cutting Out Resistance.**—In Fig. 16 can be seen the principle of the device used for cutting out resistance:

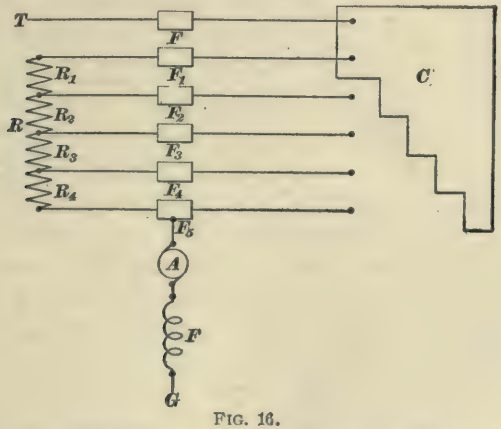



FIG. 16.

*T* and *G* are the trolley and the rail; *C* is a piece of brass or copper fastened to a drum, which can be turned around with a handle, just as a controller drum is; $F$, $F_1$, $F_2$, $F_3$, $F_4$, $F_5$

are controller fingers, which come successively in contact with plate $C$ as the drum is turned towards them; $R_1$, $R_2$, $R_3$, $R_4$ are different parts of resistance $R$ connected to the fingers $F_1$, $F_2$, $F_3$, $F_4$, $F_5$, respectively. $A$ is the armature and $F$ the field of the motor to be controlled. In the position of Fig. 16, the drum is on the first notch, with fingers $F$ and $F_1$ in contact with plate $C$, and the course of the current is $T$–$F$–$C$–$F_1$–$R_1$–$R_2$–$R_3$–$R_4$–$F_5$–$A$–$F$–$G$. On the second notch, finger $F_1$ still touches plate $C$, but the current, rather than go through the resistance $R_1$, takes the shorter circuit $F_1$–$F_2$. Plate $C$ short-circuits the resistance between fingers $F_1$ and $F_2$. Each notch that the drum advances, a new finger is brought into action and an additional section of resistance $R$ is cut out. On notch No. 5, the path of the current is $T$–$F$–$F_5$–$A$–$F$–$G$. All resistance is cut out, leaving the motor, or whatever device the drum is controlling, across the circuit in full. When the drum is thrown to the off position, the whole resistance is again cut in, step by step, thereby reducing the current, and hence the arc, when the final break is made on fingers $F$ and $F_1$.

**19. Effect of Quick Handling.** — Now, an action exactly the same as this takes place on a street-car controller, when a controller handle is advanced from the last series-notch to the first multiple notch; either one or both motors are cut out of the circuit, and are cut into the circuit again by means of a resistance coil arranged the same as the above, but with not so many steps of resistance—usually two steps, but sometimes only one. In such a case, it is easy to be seen, that, the more quickly the change is made from series to parallel, the less time the speed of the car has to respond to the increase of current due to a new part of the resistance coil being cut out. Most motormen are under the impression (and they cannot be blamed for it, because some so called road expert may have given it to them) that the change from series to parallel should be made as quickly as possible. This is not right; on some types of controller, a very quick throw-over amounts to about the same thing as

putting the controller handle on the seventh notch and running the car with the overhead switch. The resistance notches are cut in and cut out so quickly that they do no good; the current shoots up to a high value, burns the controller, weakens the motor insulation, strains the gearing, and inconveniences the passengers. To avoid the burning of controller insulation and the other injurious effects, due to excessive current and to self-induction (Art. **20**), the motorman may be pretty well guided by a due regard for the comfort of the passengers; they should have no trouble in either standing or walking about in the car. A motorman will handle his car very nearly in the right manner if he will handle it just as if it were his own personal property.

## INDUCTION.

### THREE KINDS OF INDUCTION.

**20.** As induction occurs wherever a current flows in a wire, and as induction plays a strong part for good or for bad, in at least three of the devices to be found about a car, it is not out of place here to get at least a fair idea of what it is and how it acts. Induction might well be divided into three kinds, each kind depending for its name on the manner in which the induction is set up: *simple induction*, *mutual induction*, and *self-induction.*

**21. Simple Induction.**—Simple induction is caused by a wire, forming part of a closed circuit, moving across and cutting the lines of force of a magnetic field. When a wire forming part of a closed circuit cuts lines of force, a current is set up in the wire, and this current is said to be *induced.* The current in a dynamo armature is induced, because it is due to the voltage caused by the armature wires cutting the lines of force furnished by the field core and its winding. If the wire that does the cutting is not a part of a closed circuit, it has only voltage set up in it, but this voltage is also said to be induced. The C. E. M. F. of a motor armature is

therefore an induced voltage; for the conditions are the same as in the case of a dynamo, except that the motor replaces an engine in driving the wires. Simple induction, as we have chosen to call it, is not induction in its most broadly understood sense, but it is the form in which the student is likely to first run across it.

**22. Mutual Induction.**—In the case of simple induction, the wire is the moving agent, and does the cutting of the lines of force, thereby setting up an E. M. F. It is also a fact that if a line of force cuts a wire, an E. M. F. is set up in the wire, and if the wire is a part of a closed circuit, this E. M. F. starts a current flow. In this case, the line of force is the moving agent and does the cutting. As the cutting is merely a matter of relation, it makes no difference, so far as principle is concerned, which member does the moving—hence the cutting. When a current begins to flow in a wire, the wire becomes the center of a magnetic field set up by the current; that is, the current sends out circular lines of force on all sides; and the stronger the current, the greater in number, the more far-reaching, and the closer together will the lines of force be. Those near the wire are closer together than the removed ones. When these lines of force spread out, they cut anything lying in their way, and if this obstacle is a copper wire or other conductor, it becomes the seat of an E. M. F., which, if the wire is part of a closed circuit, sets up a current in it. This current is said to be an *induced* current, being caused by the cutting of lines of force, and it, in its turn, sends out lines of force of its own, which, in cutting the first wire, called the *primary*, set up in it an E. M. F. opposed to its own. The E. M. F. in the first wire *A B*, Fig. 17, is called the *primary E. M. F.*; that in wire *C D*, forming part of the secondary circuit, is called the *secondary E. M. F.* When the primary circuit is opened and the

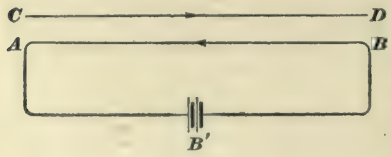


FIG. 17.

primary current is interrupted, the lines of force, due to the currents in both wires, will all flop home, and in their hasty collapse, the lines due to each current will cut through the other current's wire at a very high rate of speed. Since the amount of E. M. F. set up in a wire depends on the rate with which it cuts the lines of force, it is easy to be seen that, where there are a great many lines of force, and a great many turns of wire in each circuit, for these lines of force to cut, and these lines suddenly collapse and flop home to their respective wires in a very small fraction of a second of time, the E. M. F. induced by the rapid rate of cutting can be very high. This interaction between the lines of force of two circuits carrying a current is called *mutual induction*, and is a feature much used in alternating-current work. Mutual induction, then, causes induced E. M. F. to be set up in each of two circuits, between which there is no electrical connection. It is on this principle that one kind of wireless telegraphy is based. In Fig. 18, *A C* is a wire carrying current furnished by battery *B'*; *K* is a switch for opening and closing the primary circuit of which *A C* is a part; wire *D E* is part of a secondary circuit including galvanometer *G*. A galvanometer is a very sensitive voltmeter, having on its needle a small piece of looking-glass, which reflects a ray of light from a lamp placed in front of it; this ray of light is thrown upon a light screen or scale in a dark room, and any movement of the needle is indicated by the ray's movement on the screen, if the least current flows in wire *D E*. When the switch *K* is closed, the current in *A C* sends out lines of force, which cut the wire *D E*, set up a current in it, and cause the needle in *G* to swing out of its normal position; if *K* is kept closed long enough, the circuit in *A C* soon becomes steady, the lines of force cease to move, and therefore cease to cut wire *E D*, hence its current becomes zero, allowing the needle to

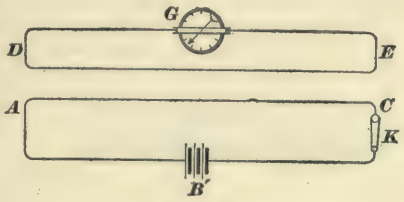


FIG. 18.

go back to its normal position. When the switch $K$ is opened, breaking the current in $A\ C$, the magnetic field collapses, the lines of force all flop home again, and, in doing so, cut wire $D\ E$ again, generating in it a current that causes the needle to swing in the opposite direction to what it did before. The details for carrying out this principle have been worked out in such a refined manner that it has been used to send signals between points several miles apart—as between a ship out at sea and some point on shore. The two points have no metallic connection, and the transmission of the measure is entirely dependent on the traveling of the lines of force.

**23. Self-Induction.**—This is marked by the fact that all of its actions and reactions take place in a single circuit—hence the name *self-induction*, "the circuit induces within itself." The induced E. M. F. and the E. M. F., which in the first place is the cause of it, are confined to one circuit. The *inducing* E. M. F., or the *primary* E. M. F., or the *impressed* E. M. F., as it is variously called, causes the current to flow, and it is the variations of this current and the resulting movement in or out of its lines of force that give birth to the induced, or secondary, E. M. F. Take a soft-iron core, and wind on it about one thousand turns of small copper wire, and a veritable nest of self-induction is created. Let such an electromagnet be connected up as shown in Fig. 19, where $A\ C$ is the electromagnet; $B'$, a battery; $K$, a switch for opening and closing the circuit; and $N$, an instrument for measuring current and called an *amperemeter*, or *ammeter*. All of the current that passes through $B'$ and $A\ C$ must pass through $N$, because it is in series with them. On closing switch $K$, and watching the needle of $N$, it will be seen that the current does not reach its full value immediately on closing the

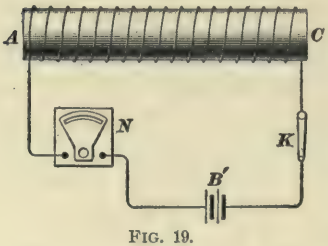


FIG. 19.

switch $K$; it may take several seconds to do so, and the needle will be seen to slowly creep up to the highest point it is to reach, and there remain until the circuit is broken or otherwise disturbed. The current seems to have to fight its way through the coil; in fact, this is just what it has to do. As soon as the switch $K$ is closed, a small current slowly feels its way through the coil; each turn of wire in the coil then sends out its lines of force, and these lines of force, in their journey outwards, cut, each one, every turn of wire in the coil and set up throughout the coil an electromotive force opposed in direction to the electromotive force that is forcing the current through the coil. The battery E. M. F., or the impressed E. M. F., has, then, to fight its way against a counter, or induced, E. M. F. Since the induced E. M. F. is due to the impressed E. M. F., it must give way to it, so that the current creeps slowly through the opposition, and finally reaches its full value; namely, that value which the ohmic resistance of the coil will allow to go through it. As soon as the current reaches its final value, the lines of force cease to move, there is no cutting of lines, and there is, therefore, no self-induction. The ammeter needle, however, does not go back to its normal position until the switch $K$ is opened, because, in this case, the primary current itself operates the meter, and the needle cannot go back to zero until this current becomes zero. In Art. **22,** Fig. 18, on the other hand, the needle of the meter depends for its action on the variation of this primary current; when the current becomes steady and there is therefore no variation, the needle returns to zero. Self-induced E. M. F. depends on the variation of the strength of the current in the circuit.

**24. Self-Induction in Straight Wires and Spirals.** A given length of any kind of wire stretched out in a straight line has a certain amount of ohmic resistance that is independent of the amount of current the wire carries, except in so far as the current may heat the wire and raise its resistance in that way. This same straight wire has also a certain

amount of self-induction; if the piece of straight wire is wound up into a spiral, the ohmic resistance of the wire remains the same—except in so far as bending the wire may harden it a little, thereby raising its resistance—but the spurious resistance and the self-induction are increased a great deal. As a practical example: If the wire wound on a street-car armature and field were stretched out straight, and 500 volts applied to its ends, a current of nearly 1,000 amperes would flow through it, and an ordinary street-car fuse would blow immediately; but when the wire is wound up into a coil, having an iron or soft-steel core, as in a motor, it takes the current a little time to work up to its full value, and perhaps before it can do so, the motor starts, generates C. E. M. F., and cuts the current down before it can do any harm. Such is the case in street-railway repair shops, where it is a common but bad practice to run trucks around by connecting one motor up and applying the voltage directly from the trolley, by means of a hooked wire attached to a wooden pole. This practice is a rather dangerous one, for should the motor, for some reason or other, fail to move, there would be a heavy flash, which might burn the operator's eyes. One might as well try to suddenly stop a train running at high speed as to force a current through a circuit of great self-induction in a very short period of time; the current will take almost any path through good insulation, rather than try to overcome instantly any self-induction. On this fact depends the action of the lightning arrester.

---

### THE LIGHTNING ARRESTER.

**25. Principles of the Lightning Arrester.**—The fields on large street-railway dynamos are electromagnets of great self-induction, and on some of these machines the field current requires a quarter of a minute or more to creep up to its maximum value, so that it is easy to see what great opposition the impressed E. M. F. has to send its current against. Now, the E. M. F. of lightning is almost beyond our power of conception; it is up in the millions of volts,

and when lightning strikes a circuit something has to give way to give it a path to the ground. One side of the winding of a street-railway motor or dynamo is always grounded, because the earth, together with the rails and whatever water pipes and gas pipes there may be in the vicinity, act as the return path of the current to the dynamos in the power houses. (Circuit connections are taken up in another Paper.) The overhead work and dynamo or motor connections on a street-car line form a comparatively easy path for the lightning discharge to follow to the ground. The lightning discharge moves along this path smoothly, until it gets to the machines themselves; there it bumps up into a nest of self-induction that flatly refuses to let it pass; but the discharge, having millions of volts of pressure behind it, must go somewhere, so it jumps right through the field or armature insulation to the iron frame of the machine. The path through the fields and armature has a great deal of induction, and is hence called an *inductive path;* the path through the armature or field insulation has no induction, and is called a *non-inductive* path. Without going into details, it can be stated that there are means, within perfect control, of artificially producing an electric discharge of very high voltage, and of the same general character as a lightning discharge. In Fig. 20, *T a G* is a piece of wire bent into a loop, one end of which sticks up in the air, and the other end of which goes to the ground at *G*. The path *T–a–G* is an inductive path, because the loop *a* has self-induction; the path *T–o–G* is a non-inductive path, because it is an air gap and has no self-induction. If, by means of the discharge machine, a discharge of high voltage is sent into the wire at *T*, the discharge will jump across the air gap at *o*, rather than force its way through the self-induction of the single loop *a*, and reach the ground in that way. A lightning discharge will always take a non-inductive path, and the mission of the lightning arrester is to provide to the ground a non-inductive path of

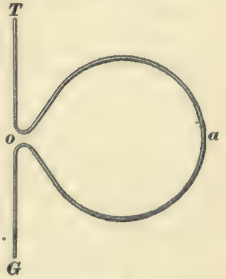


FIG. 20.

as low ohmic resistance as possible, so that the lightning will go that way instead of through the motor fields or armature, to puncture their insulation. In Fig. 21, $T$ is the trolley wire and $G$ is the rail; $L$ is a very primitive form of lightning arrester and $A$ and $F$ are the armature and field of the motor to be protected. $L$ consists of two brass plates held so close together that their distance apart is less than the thickness of the thinnest insulation to be found on the motor to be protected. One of the plates of $L$ is connected to the trolley wire before it reaches the motors or the controllers, and the other plate is connected directly to the ground. A discharge of lightning coming in at $T$ jumps across the air gap in $L$, and goes to ground at $G$. Fig. 22 shows an arrangement that differs from this in two details. In the first place, the two plates are made comb-shaped, because electricity seems to jump between corners better than between plain surfaces; also, this construction increases the amount of plate surface exposed. The second detail marking a difference is found in the spiral $S$, which constitutes what is called a "kicking coil" or "kicker." This kicker is placed in circuit ahead of the motors, and increases the self-induction of the motor circuit, and thus, in a measure, further protects them. As a matter of fact, it is supposed to choke back the lightning discharge before it reaches the controllers or motors, and turn it into the lightning-arrester circuit. The motors are thereby saved the duty of turning off the discharge, and the controllers, through which the discharge must pass before it can encounter the self-induction

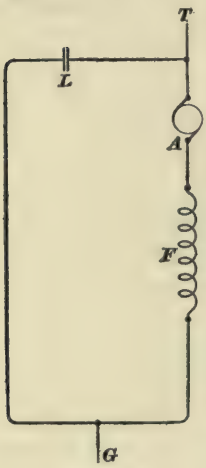


FIG. 21.

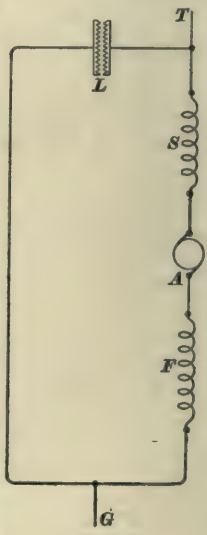


FIG. 22.

of the motors, are more perfectly protected. The efficiency of the lightning arrester depends very largely on the thinness of its air gap; to be at all effective, this air gap must be thinner than any of the insulation to be found on the motors or on the controllers. Another very important point is to have as few bends as possible in the wires leading to and from the lightning arrester. Every bend adds to the induction of the circuit, and offers an additional inducement for the discharge to take some other path. The path from the trolley wire to the lightning arrester and thence to the ground should approach a straight line as nearly as possible.

**26. The Arc in the Air Gap.**—The air gap in a good lightning arrester is not over $\frac{1}{64}$ to $\frac{1}{32}$ of an inch; when it is beyond this, the arrester ceases to be reliable on 500-volt street-railway circuits. Now, the 500-volt pressure of a trolley wire will not jump across the gap in an arrester; but when the lightning discharge jumps the gap, the line voltage is strong enough to follow it, and does follow it, and unless some provision is made for extinguishing the arc, the arrester will be burned so badly as to make it useless. To extinguish the arc that follows the lightning discharge, several devices have been invented, of which, perhaps, the magnetic blow-out is most widely used. A number of these devices will be taken up in connection with lightning arresters.

**27. The Magnetic Blow-Out.**—One method of putting out the arc is by means of the *magnetic blow-out*, so called because a magnet is used to blow out the arc. In Fig. 23 is

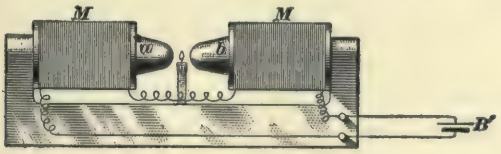



FIG. 23.

shown a powerful electromagnet energized (magnetized) by coils, *M*, *M*, supplied with current from a battery *B'*. Pole pieces *a*, *b* are so shaped that the lines of force between them

are very dense, or close together. If a lighted candle is moved across the lines of force between these pole pieces, the flame will refuse to burn straight up through the dense part of the field, but will be deflected one way or the other —either towards or away from the observer. If the exciting circuit is broken, and the lighted candle placed midway between the centers of the pole pieces, as shown in the figure, the flame will, upon turning on the current, deflect to one side or the other, according to the polarity of the pole pieces. If a circuit, carrying current and voltage enough to maintain an arc half an inch long, is broken between the pole pieces, the arc will be promptly deflected so far out of its course as to break it. This arc-extinguishing ability of the magnetic field has been successfully applied to making controllers and other devices more durable, and it also accounts for the fact that fields and armatures are comparatively seldom so badly burned that they cannot be repaired at light cost and used again.

---

### THE INDUCTIVE DISCHARGE.

**28. Cause of Inductive Discharge.**—The preceding articles have considered self-induction and its action when the circuit is closed, and the current forced through against the action of the self-induction. The equally important question will now be considered of how self-induction acts, when the current, at its full value, is suddenly interrupted by breaking the circuit. If one does a certain amount of work in carrying a weight to the top of a house, the work done is stored in that weight, and the weight can be made to give back nearly all of the work put into it, by arranging a suitable mechanism for the weight to operate in its descent to the level from which it was carried. Now, it has been shown that, in order to force a current through a coil against the opposition of the self-induction, the battery must do work; and this it does, in sending out the regular lines of force to establish a magnetic field around the coil. All the work done by the battery is stored in this magnetic field; and, if the magnetic field is given a chance to do so, it will give out

in some form or other the work stored in it by the battery. The lines of force, when they spread out, might be conceived to go out under tension, just as if they were so many rubber bands, and when the force that holds them out (the action of the current in the wire) is removed, they come in, and, in doing so, give out the work stored in them. The way they do the work is to cut the turns of wire in the spiral, and generate it in an E. M. F. that is of the same polarity as the battery. When the lines of force spread out, the induced E. M. F. *opposes* that of the battery; but when the circuit is opened and they come in, the induced E. M. F. *assists* that of the battery. This is why such a long flash is obtained when the circuit of an electromagnet is broken. The lines of force all coming in so suddenly generate a very high induced E. M. F., and it is this induced E. M. F. that causes the arc to be long. If the wire on the electromagnet is stretched out straight, and the same amount of current sent through it, the arc will hardly be noticeable when the circuit is broken, because there is no self-induction.

**29. Precautions Against Inductive Discharge.**— On some street-railway generators, the induced E. M. F. generated when the field circuit is suddenly opened, is so great that the field insulation is often pierced by it, and some provision has to be made for reducing the current before interrupting it entirely. This is generally done by opening the field circuit through a lamp circuit first, and then opening the lamp circuit. In Fig. 24 is shown the connection of these lamps in the field circuit of a dynamo or a shop motor; $T$ is the trolley; $G$, the ground; $F$, the field winding; $K$, an ordinary knife switch for opening

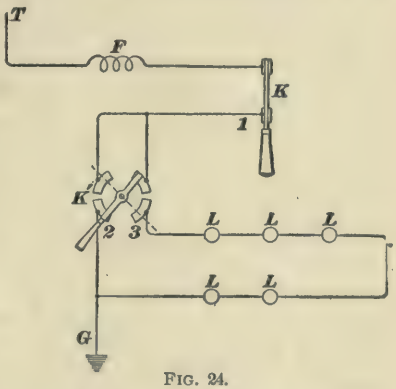



FIG. 24.

the field circuit; $K'$, a two-way switch for throwing the lamps in or out; and $L, L, L, L, L$ are a series of five lamps. When the machine is running, the switch $K'$ occupies the full line position, and the course of the current is $T$–$F$–$K$–$1$–$2$–$G$; when the machine is standing still and it is desired to break its field without puncturing the insulation, switch $K'$ is thrown over to the dotted position, and the course of the current is then $T$–$F$–$K$–$K'$–$3$–$L$–$L$–$L$–$L$–$L$–$G$. This places the five lamps in series with the field, reducing the field current, and consequently the magnetic field, very much; so that, when switch $K$ is opened and the field circuit entirely broken, the induced E. M. F. of the field is not enough to break down the insulation. If the switch $K$ is opened before $K'$ is thrown over to the dotted position, the induced E. M. F. is apt to jump to ground through a shorter path by puncturing the insulation.

**30.** Fig. 25 shows a simpler connection for the lamps, but it accomplishes the same thing without the use of any special form of switch. When the switch tongue is thrown to the right, the course of the current is $T$–$F$–$K$–$G$; when it is

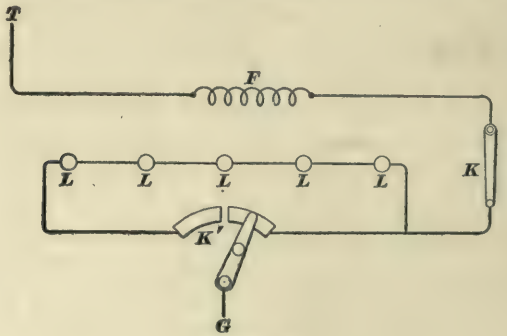



FIG. 25.

thrown to the left, the course is $T$–$F$–$K$–$L$–$L$–$L$–$L$–$L$–$K'$–$G$ through the lamps. One precaution to take is to be certain that the switch jaws are so long that the switch tongue, when it is thrown over, does not fail to make contact with one jaw before it breaks contact with the other jaw, otherwise

the circuit will be opened entirely—a condition to be avoided. When the lamps are cut into circuit, the induced E. M. F., due to the decrease in current, discharges a current through the lamps and they glow very brightly for a moment.

**31. Examples of Inductive Effects in Motor Circuits.**—Let us see, now, what all this talk about induction has to do with a motorman's handling his controller properly. In a motor and its circuit, there are the armatures and fields with their many turns of wire wound round iron cores. What better conditions could there be for self-induction? Each time the motorman advances the controller drum a notch, the self-induction enters a protest against the increase in current so suddenly imposed; and when the drum is thrown around from series to multiple too quickly, increasing the current value three or four times, perhaps, the motorman is trying very hard to "throw that tomato through a stone wall," for the self-induction revolts forcibly at such an imposition. Moreover, the following weaknesses are liable to develop: If the motor commutator is not in good condition, there is apt to be sparking at the brushes; whenever brushes spark, they give off a vapor laden with carbon dust and vaporized copper, and this vapor is a fairly good conductor. The current, then, rather than allow itself to be forced, under impulse, through the great self-induction of the motor fields and armatures, prefers to take the non-inductive path across the vapor to the motor frame; the result is a grounded brush holder, field, or commutator. The same thing will happen if carbon dust is allowed to collect around the end of the commutator; the current will short-circuit through this dust to the commutator shell, which is generally grounded. If the motors are clean and in good condition, the current will pick out some weak spot in the insulation of the controller, which is generally grounded through the dash rail and the brake rigging, and blow up the controller. The current seems to be willing to go anywhere, or to do anything, in preference to fighting self-induction under a time limit.

**32.** The effect of throwing the current on and off without giving the car a chance to move, was considered at some length in Art. **11,** but it may be added that street-car motors are more liable to be grounded by the inductive discharge, because one side of the motor is already grounded. As an actual example of the high voltage induced when a motor circuit is suddenly broken under load, the following is given. A series of experiments were being made on a controller that broke its arc in oil contained in a tank. The controller was tested on a pair of motors that were insulated from the ground, and the test proved to be very satisfactory; but when the controller was connected up to the motors on a car, it was impossible to get the car out of the house. At the end of the house was a short curve, where it was necessary to throw off the power; every time the power was thrown off, a field or an armature was punctured; field after field was put in, only to suffer the same fate, and it was not until some provision was made for looking after the self-induction of the circuit that the car could be made to run a trip. The armatures and fields of these motors were extra well insulated, because such action as this was looked for; so some idea can be formed of the E. M. F. induced when a motor circuit is suddenly ruptured. To make matters worse, the E. M. F. induced when the resistance of a circuit is increased, or the circuit is entirely broken, is of the same polarity as the line voltage, so that the two E. M. F.'s being in series, assist each other to increase the induced current. Self-induction treated with respect and properly provided for is a good thing in a motor circuit, for, to a certain extent, it prevents the motors from being abused.

---

EXPLANATORY.

**33.** Before closing the last Paper on *Motor Principles* it might be well to give the reader an idea as to why it is that a steam engine has to pull and tug so hard to keep a dynamo armature turning. The reason, which is simple, but not generally known, is this. When two magnets are placed

with their two unlike poles together, it requires some work to pull them apart; if the magnets are large and powerful, it requires a great deal of work to pull them apart; if they are large enough and powerful enough, it takes a steam engine to pull them apart, and this is just what the steam engine attached to a dynamo armature is doing all of the time. The more current the dynamo carries, the more powerful are its magnets, and the harder the work the steam engine has to pull the armature round against the attraction of the field. In case of a short-circuit, the current is so large, and the pull between the magnets is so strong, that belts and clutches are often broken and the engine even pulled from its foundation. This fact is explained, because it bears directly on an important feature to be considered in a later Paper, whereby the dynamo properties of a street-car motor can be used to stop a car even when the power is off and the brakes useless.

---

### CONCLUSION.

**34.** In the foregoing pages, an attempt has been made to present the subject to the reader in a manner that will give him some basis to think on, and prepare him, as a result of thought and study, to solve, in an intelligent manner, some of the problems presented to him every day in his capacity as motorman, conductor, inspector, or road boss, as the case may be. The reader may have been tempted to ask himself, What is the use of knowing all this? In itself and by itself, this knowledge would be of little use, for it would neither put a derailed car on the track nor give a cripple power to run into the shed alone. A knowledge of the foregoing principles, together with their practical application, will enable a man that is fortunate enough to have a man's share of brains, although he may not have the education, to think out for himself things that have never been written about. The facts in these lessons have been gleaned from conversations with intelligent railroad men—not presidents, managers, superintendents, and such like, but from those men that obey orders and know how to.

# CAR EQUIPMENT.

(PART 1.)

## CAR APPLIANCES.

**1.** It is now in order to take up the several devices which go to make up a car equipment and to see just how far the principles, learned in the preceding lessons, apply to the care and operation of these devices. The most natural order in which to treat the devices is the order in which the current passes through them, in its course from the trolley wire to the ground.

**2.** The devices, in the order named, are the *wheel*, *pole*, *base*, *roof wiring*, *hood switches*, *wall wiring*, *fuse box*, *lightning arrester*, *controllers*, *resistance coils*, *motors*, *trucks*, and *wheels*. Fig. 1 gives the general path of the current in passing through these devices: *a* is the trolley wire; *b*, the wheel; *c*, the pole; *d*, the socket; *e*, the base; *f*, the terminal for connecting the roof wiring; *g* and *h*, the overhead switches; *i*, a wire which passes from the overhead switch down through the end wall of the car to a point beneath the floor; *j* is the fuse box; *k*, the lightning arrester; *l l*, a wire from the trolley post of one controller to the trolley post of the other controller. *m*, *m* are the two controllers; *n n*, a wire running from the ground post of one controller to the ground post of the other controller; *o*, *o*, two wires spliced on to wire *n n* and connected to the frames of the two motors *p*, *p*.



For notice of the copyright, see page immediately following the title page.

From the motor frames the current passes through the bearings to the axle, thence through the wheels *w*, *w* to the rail.

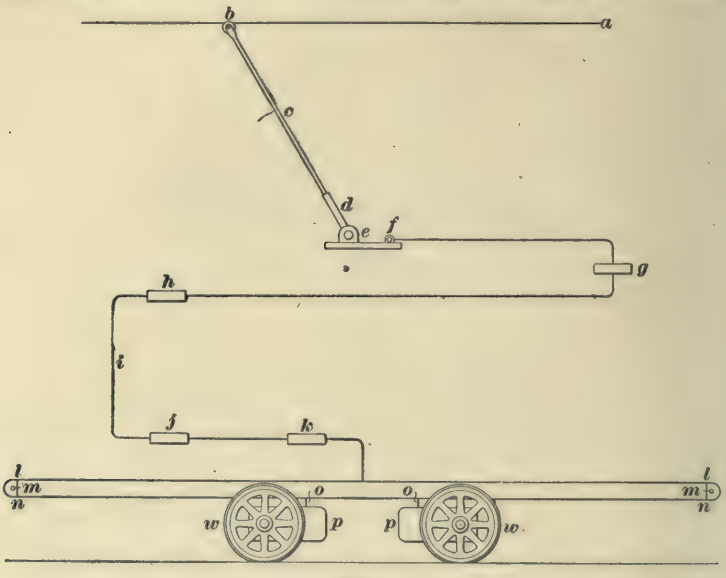



FIG. 1.

The order of the current flow is, then, in the same order as the letters. The heater circuits, the light circuits, and the bell circuits will be considered by themselves.

---

## THE TROLLEY.

**3. Parts of Trolley.**—The trolley pole, generally called the **trolley,** comprises five distinct parts: the *pole* proper, the *ferrule*, the *harp*, the *contact springs*, and the *wheel.*

**4. The Pole.**—The *pole* proper, which is from 12 to 15 feet long, is about 1½ inches in diameter at the large end, and holds this diameter for about 2 feet of its length, when it begins to taper and gradually draws down to a diameter of 1 inch. Most poles are steel, hard drawn by a special patented process, and they offer a great deal of resistance to being bent; when once bent it takes hard work to

straighten them. A slight bend in a pole is generally straightened by using a post with a hole in it as a vise and bending by hand; but severe bends should be taken out by sledging cold. A pole should not be heated to straighten it, as the character of the steel is such that the part heated

FIG. 2.

becomes soft and easy to bend. Poles generally in use cost from $1.50 to $2.00, according to the length and quality. Fig. 2 gives an idea of the straight and tapered part of a standard pole.

**5. The Ferrule.**—As a rule there is provided a *ferrule*, which is designed to receive the trolley rope, and which is made of a brass or malleable-iron ring with an eye in it to take one end of the rope. It is secured to the small end of the trolley pole, as shown in Fig. 3, where *p* is one end of the pole; *f* is the ferrule; and *s*, one end of the harp stem; *t t* is a pin passing into the pole and stem through the ferrule. This pin fits the ferrule loosely so that the latter may be free to turn when the pole is swung around, but it is forced into the pole and harp stem and riveted there by means of rivets *r*, *r*. A ferrule is not used on all roads, its place being taken by an eye cast in a projection on the harp itself, as shown at *e*, in Fig. 4. In either case, the eye hole should be well rounded out to avoid its cutting the rope, a thing which happens very often and causes a great deal of inconvenience. Many devices have been made and tried to prevent a trolley rope from breaking off at the point where it is

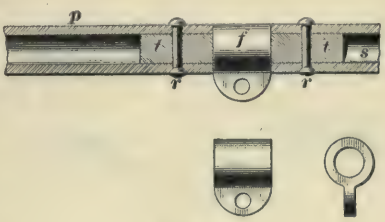



FIG. 3.

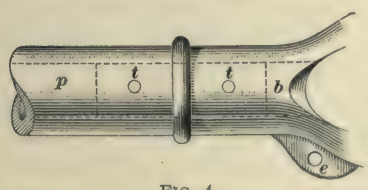



FIG. 4.

fastened to the pole, but none of these devices have been a success. In some cases they have been badly adapted to quickly replacing a rope, and in other cases apt to catch in the frogs and hangers, should the pole fly off. When the cost of trolley rope, which is from 15 cents to 30 cents per pound, is taken into consideration, it can be readily seen that any device which would save 25 or 30 pounds of rope per day will find a place on the market. Fig. 4 shows the manner of attaching the harp directly to the pole. In this figure *b* is the harp, *p* is the end of the pole, and *t*, *t*, the rivets by which the two are fastened to the connecting pin; also, at *e* is shown the hole to receive the trolley rope.

**6. The Harp.**—*Harp* is the name given to the fork which holds the wheel and the axle for the wheel to turn on; it also holds the two contact springs, one of which is shown at *S*, in Fig. 5. In Fig. 5, *b* is the harp proper; *a*, the axle for the wheel to turn on; *s*, *s*, the two springs on either side of the harp; and *c*, *c*, two cotter pins which pass through two holes drilled in the ends of the axle and serve to keep the axle in place. It has been the custom to make trolley harps of brass, but malleable iron is fast replacing it, because it is cheaper and stronger, and because it offers no temptation to thieves. Brass is made of the proper mixture of copper, tin, and zinc; malleable iron is cast iron which has been subjected to heat for several days in the presence of a certain kind of ore called hematite. It can be easily bent by a blow when cold, but cannot be hammered when hot. Cast iron will break if subjected to a blow under any

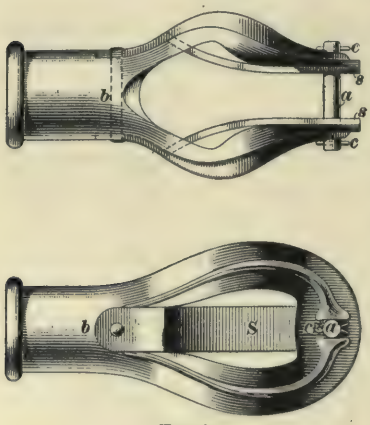


FIG. 5.

condition. The main points which govern the selection of a harp are narrowness and smoothness; all edges should be nicely rounded off to avoid catching in the line work when the pole flies off the wire. The selection of a good harp means a great saving in poles, ropes, and overhead work.

**7. Contact Springs.**—The *contact springs* are pieces of spring copper which are riveted to the sides of the harp, and which have holes in their ends for the axle to pass through. These springs press against the sides of the wheel and serve, not only to take the current from the wheel to the pole, but also to act as washers to lessen the end wear of the wheel. Fig. 6 shows how the springs are shaped. If the springs are left off an ordinary harp, all of the current which the car gets must pass through the bearing surface between the wheel and the axle, and as soon as wear makes the bearing the least bit loose, more or less burning takes place between the wheel and axle and these parts become blistered. This cuts out the bearings and causes the wheel to give forth a very disagreeable, humming, rattling noise.

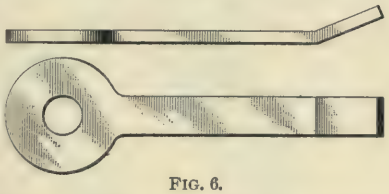


FIG. 6.

**8. The Wheel.**—The trolley wheel is a device upon which a great deal of experimenting has been done to determine the best shape of wheel and the best composition of metal consistent with long life of the wheel and trolley wire. Some wheels wear out sooner than others, and some are harder on the trolley wire than others. A wheel that is too soft will wear out very soon; on the other hand, a wheel that is too hard, or that has a poorly shaped groove, will scrape the trolley wire at curves and turn-outs. Almost all roads go through a certain amount of experimenting to decide what shape and metal are best adapted to the overhead construction. A good lesson can be learned from careful observation of worn-out wheels; some wheels

wear out most in one place and some in another; the same make and shape of wheel will wear differently on different branches of the same road. If both flanges of the wheel persist in getting sharp, it indicates that the groove is too deep, or too narrow, or both. If the groove wears down to one side, the indications are that the pole is in crooked, or that the harp is crooked, or that the trolley wire is out of center. Too much stress cannot be laid on the importance of getting the pole so adjusted that when it is in its normal position, the trolley wire rests on the bottom of the groove and runs parallel to the flanges. Fig. 7 shows a

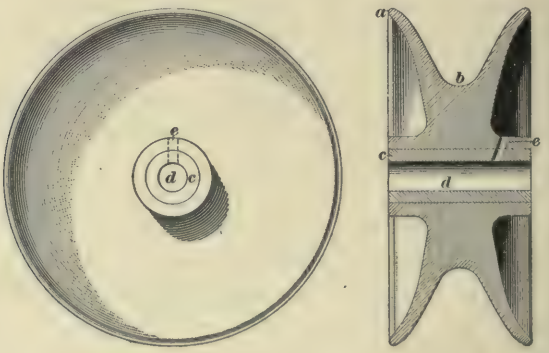



FIG. 7.

trolley wheel much used in this country; *a* is the flange; *b*, the groove; *c*, the bushing or bearing; *d*, the hole through which the axle passes; and *e*, the hole for oiling. The bushing, or bearing, is a brass spiral sleeve, filled with graphite, and can be forced in or out of a wheel when wear makes it necessary to do so. The bushing is a very particular part of a wheel and should be well made and well kept; to keep a bushing in good order, it should be well oiled every fifteen or twenty miles that the car makes; for when it is taken into consideration that a trolley wheel turns around about five thousand times every time the car runs a mile, and that cars make several miles an hour, the importance of a perfect bearing is easy to see. On roads that make any pretension to looking after their trolley wheels, a platform is

built which overhangs the car roof, so that the wheel may be oiled every time that the car passes that way. Fig. 8 indicates the kind of platform referred to. When oiling a wheel, a piece of waste should be held under it to prevent the excess of oil from falling through on to the roof of the car, where, in course of time, it makes a mess. When a wheel is allowed to run dry, the hole in the bushing soon wears to an oblong shape, allowing the wheel to vibrate and emit a chattering noise. The same noise may be caused by a wheel having flat spots in the groove. These flat spots may be due to the wheels sliding along for want of oil instead of turning; in other cases they may be due to some imperfection; or they may be due to soft spots in the metal of which the wheel is made. In any case the wheel should not be run, but should be taken out, and, if there is any stock left in it, turned down to be used again.

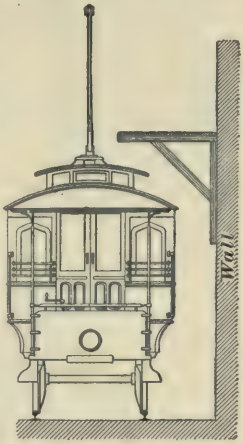



FIG. 8.

---

## TROLLEY STANDS.

**9. General Description.**—The pole fits into, and is held by, a device called the *trolley stand*, which gives the pole freedom of motion in two directions: up and down, to enable the pole to adjust itself to stretches of wire varying in height above the ground; and sideways, so that the pole may be swung around when the direction of motion of the car is changed, and also that it can follow the wire freely in going around curves. The trolley stand has two members: the upper member, which holds the pole and is free to turn around the lower member in a plane parallel to the surface of the earth, and the lower member, called the base, which is screwed to the board or bridge and acts as a center for the upper member to turn around on; this lower member

also receives the wire which leads the current from the trolley stand to the controlling devices. The upper member includes the *socket*, the *spring*, and the devices for adjusting the tension on the spring.

**10. Simple Trolley Stand.**—In Fig. 9, *a* is the *base*, the upper part of which forms a pin *t*, over which fits the lower part of the casting *n*; *b* is the socket proper; and *s*, the spring by means of which the pole is made to press against the trolley wire. In the full-line position given in the figure, the pole stands straight up; at its neutral point; the coils of spring *s* are relaxed and therefore exert no influence on the socket casting. When, however, the pole is pulled over to the dotted position, socket casting *l* raises and pulls the coils of spring *s* out, thereby bringing that spring into action. This figure is merely symbolical and is given to show the relation of the several parts.

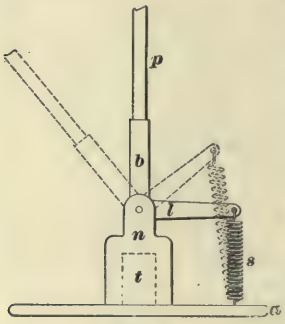


FIG. 9.

**11. The Socket.**—Fig. 10 shows the construction of a *socket*, how it grips the pole, and the means for tightening it. In this figure, *p* is the pole and *N* the socket; *b*, *b*, *b*, *b* are lugs cast on to the side of the socket to receive setscrews or bolts.

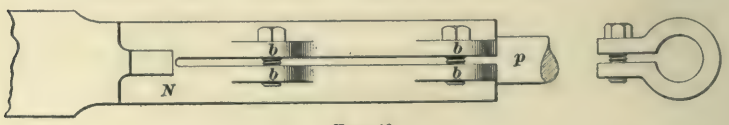


FIG. 10.

The distance apart of the jaws or lugs *b*, *b* allows the socket to take poles the bases of which vary in diameter. When the base of the pole is so small that it fails to be held tightly, even when the jaws of the socket are drawn together, a lining of some sort must be used. A piece of tin or sheet iron

may be used for this purpose. If iron cannot be had, several layers of paper may be used, provided it is arranged so as not to insulate the pole from the socket. The hole in the socket is made to draw up tight on a $1\frac{1}{2}$-inch pole base.

**12. The Nuttall Trolley Stand.**—Figs. 11 and 12 show one form of Nuttall stand very popular with the trade. *G* is the socket proper, and *f*, *f*, two wings forming part of the

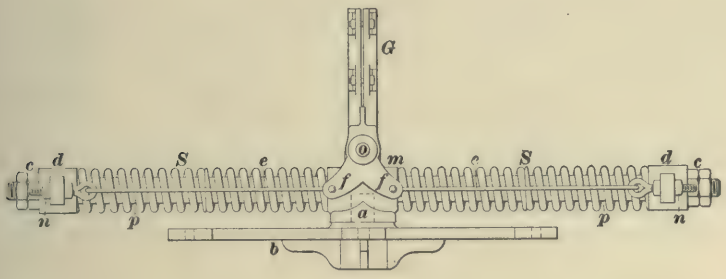



FIG. 11.

socket casting provided to receive one end of adjusting rods *e*, *e* the other ends of which pass through cup castings *d*, *d* to receive adjusting nuts *n*, *n*. On this form of trolley

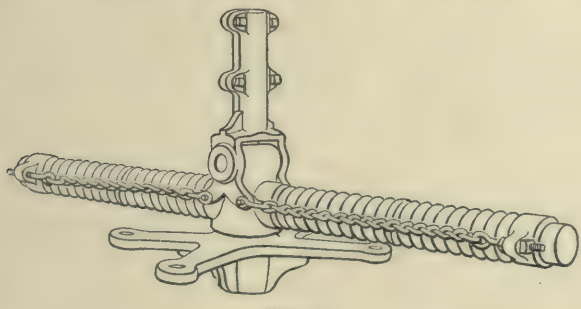


FIG. 12.

stand the pole may either be rocked over independently or can be swung around with the upper member *m*. Casting *m* also receives the two guide-rods *p*, *p*, over which work springs *S*, *S*; *c*, *e* are the tension rods; *d*, *d*, the compression cups; and

*c*, *c*, the nuts for changing the tension. The general action of the device is as follows: When the pole is pulled one way or the other, one pair of tension rods (only one of each pair is shown in the figure) pulls on one compression cup, compresses one of the springs, and produces the desired pressure of the wheel against the trolley wire. To increase the tension, that is, the force with which the wheel is pressed up against the trolley wire, tighten up nuts *c*, *c*; this will cause some slack in rods *e*, *e*, so that nuts *n*, *n* will also have to be taken up. To render springs *S* entirely inactive, remove nuts *n*, *n* altogether. In the Nuttall trolley it is possible either to swing the trolley around or to let it stand straight up and rock it over in the opposite direction. All trolley stands do not permit of this, but it is a good feature, because in case of a pole being bent, as shown in Fig. 13, rocking the pole over

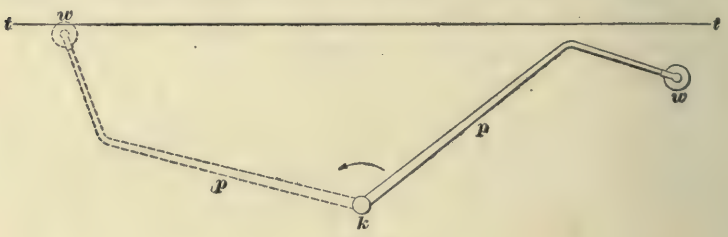



FIG. 13.

does away with the disadvantages of the bend, whereas swinging the pole will do no good at all. To take a stand of this kind apart, that is, to take the upper member from off the lower member, bend the pole down one way as far as it will go and tie it; the upper member can then be lifted off without danger to life or limb. To take the upper member apart, let the pole come to the straight-up, or neutral, position, where there is very little compression on either spring. Nuts *n*, *n* can then be removed, rods *e*, *e* disconnected, and the axle, around which the socket casting turns at *o*, taken out. Sometimes instead of the rods *e*, *e* there are chains, as shown in Fig. 12; this goes to prove that the force acting along the rods is always a pull, never a push. In other words, the rods are always under tension, never under

compression. The springs, on the contrary, are always under compression and never under tension.

**13.** Fig. 14 shows the difference between a spring under tension and a spring under compression. Fig. 14 (*a*) shows spring *s* under tension, because weight *w* is attached to a rope which passes over pulley *p* and hitches to one end of the spring. Fig. 14 (*b*) shows spring *s* in compression,

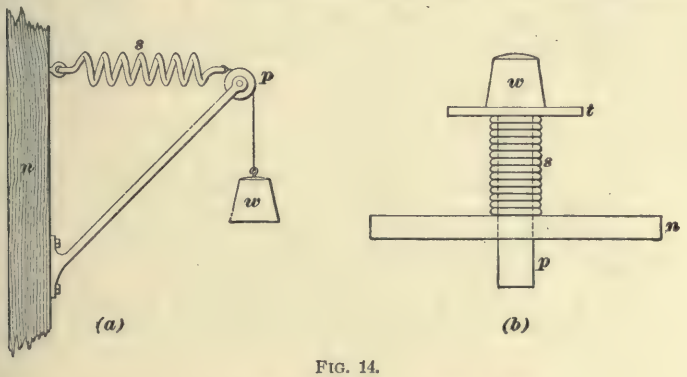



FIG. 14.

because it supports weight *w* on top of it. Upon removing weight *w*, spring *s* will become longer. On a car the springs which hold the brake shoes away from the wheels when the brakes are idle, are tension springs; the springs under the head of the bell buttons are compression springs. On the trolley stands, sometimes the springs are compression springs and sometimes tension springs.

**14. The T. H. Trolley Stand.**—Figs. 15 (*a*), 15 (*b*), and 16 show a form of trolley formerly in good repute; Fig. 16 is a perspective view of the upper member of this trolley stand, and in the figure the pole is in its neutral position. Upon bending the pole to the left, rocker *R* winds up the straps attached to the spring frames and pulls out the battery of springs *S*. To increase the tension, nut *n* must be tightened up. To decrease the tension, nut *n* must be loosened. To take the base apart, rock the pole down as far as it will go and stick a spike or other piece of iron in between the lower part of rocker *R* and the upper part of

casting $c$; then slowly let the pole up, until the obstruction bites and the other member can be worked on without

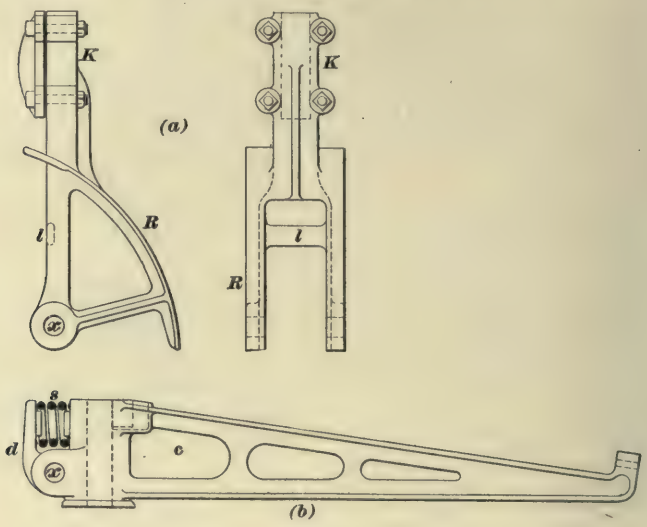



FIG. 15.

danger. To take the upper member to pieces, it is only necessary to remove tension rod $t$ and axle $x$. It can readily be seen that with this style of base the trolley pole cannot

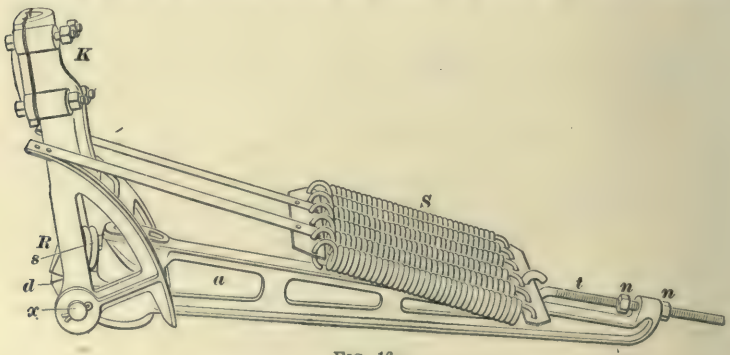



FIG. 16.

be rocked over, but must be swung around with the upper member. In Fig. 15 ($b$), a spring $s$ may be seen on main casting $c$. There is a projection on one side of the main

casting and this projection goes into one end of the spring; an iron dog *d*, which moves around the same center as the rocker casting *R*, has a slight projection which goes into the other end of spring *s*. In case the trolley rope breaks or for any other reason the pole flies up, rib *l* of casting *R* compresses spring *s* and relieves the trolley stand of the great shock it would otherwise get.

**15. The Johnson Trolley Base.**—Figs. 17 and 18 show one type of Johnson base. This base differs from the pre-

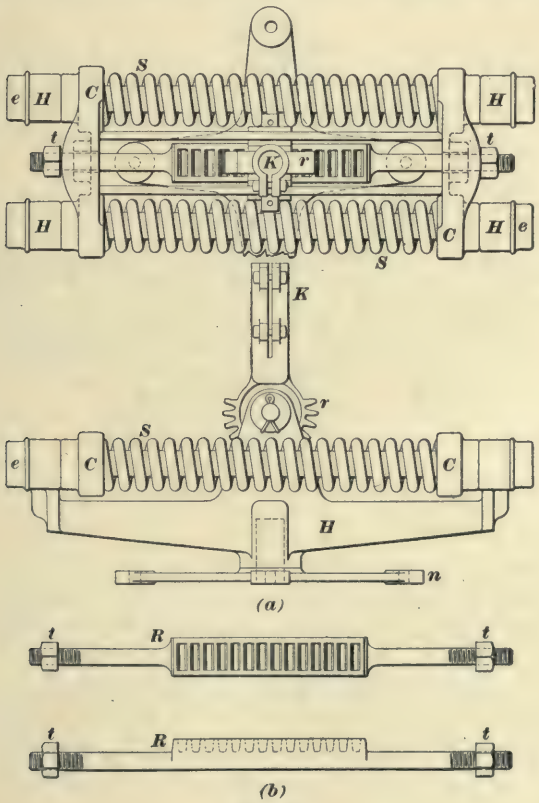



FIG. 17.

ceding ones mainly in that there is a rack and pinion employed in it to take the place of connecting-rods or chains.

At the lower end of the socket casting, is a pinion *r* which works in the rack *R*, the ends of which are threaded to take nuts *t*, *t*. Castings *C* are compression cups or yokes and they receive the ends of the compression springs *S*, of which there are two. When the pole is pulled one way or the other, pinion *r*, turning around its center, and engaging rack *R*, pushes the rack along; since the rack passes through castings *H* and has a nut *t* on each end, whenever the rack moves, one of these castings must move, and when it does so, it bears against compression cups *C* and compresses springs *S*. This

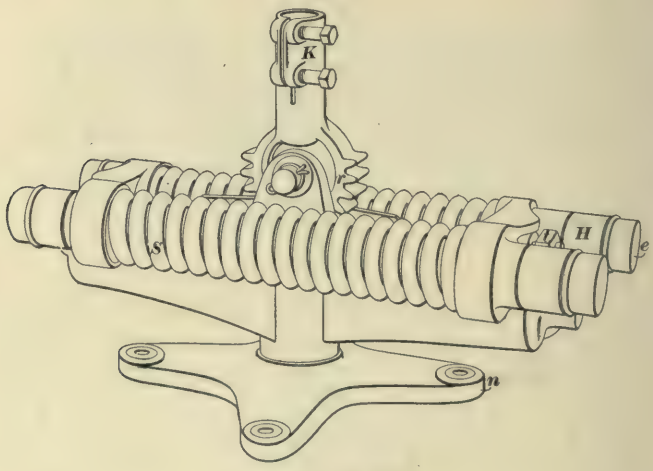



FIG. 18.

base allows the pole to be swung around or to be rocked over. The normal position of the socket, when not under tension, is pointing straight up in the air; when in this position the center of the rack should be in line with the center of the base, and the two nuts *t*, *t* should be at the same distance from the end of the rack *R*. If this condition is not satisfied, it will be found that the pole, when in the neutral position, that is, the position when it is not under pressure, will not stick straight up, but will lean to one end of the car or to the other, and the tension will be stronger when the pole is rocked one way than when it is rocked the

other way. Motormen and conductors soon learn this fact and find out that sometimes the tension on the pole can be very much improved by simply rocking the pole over. To increase the tension on both sides, both nuts *t*, *t* should be tightened up the same; the effect of this is to draw the yokes together and put more tension on the springs. The pinion and rack should be greased occasionally, to prevent wear.

**16. The Duncan Base.**—Fig. 19 gives the form of base known as the Duncan base. It is somewhat similar to the

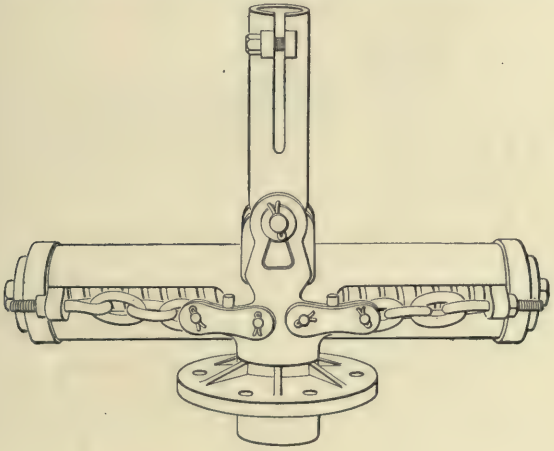


FIG. 19.

Nuttall base, but differs in that the compression springs move inside of an iron sheathing instead of on an arbor. The sheath is slotted on the side to serve as a guide for the compression cup, only the lug of which can be seen in the figure. This trolley base is not used very much.

**17. The Anderson Base.**—Fig. 20 shows a style of base similar in action and design to the T. H. base. Its method of adjustment is also the same.

**18. General Remarks.**—The pressure with which the pole presses against the trolley wire varies from 12 to 20 pounds, according to the local conditions and to the

speed at which the car is to run. If the tension is too light, the pole will be continually jumping off the wire at every kink or turn; if the tension is too great, it causes unnecessary wear of the trolley wire, wheel, and axle, and also makes it much more difficult to get the wheel back on the wire after it has jumped off. A car should never be run with the pole turned the wrong way, because, if in the shed, the pole will be bent and rendered useless for the time being should it come off; if out on the road, the pole

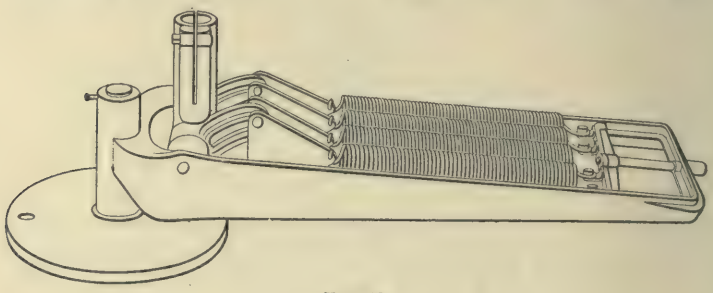


FIG. 20.

is liable to get caught in a frog or hanger and push the line down. On many roads there is a severe penalty attached to the offense of running a car with the pole turned the wrong way, even when there is a conductor or trolley boy watching it. If the pole comes off while the car is in motion, it should be pulled down as soon as possible and the motorman given the signal to stop. It should not be replaced until the car has come to a stand, because in doing so there is danger of striking a span wire or frog and doing serious damage to the pole, base, or the line. Such a thing has happened as the pole being jerked out of the socket and knocking the driver of a passing team on the head. Ordinarily an old motorman can tell the instant the pole goes off, if it happens to do so while the power is in use, because not only does the car halt a little, if on a level or on an up grade, but the sound that the gears make changes its character wherever the car may be. As long as the power is in use, the gears run the car and emit a sound more or less grinding; as soon as the power

is off, the car runs the gears, and their lost motion causes the noise to become more of a clang. Of course, if the car is coasting along, none of these symptoms are noticeable, and, unless it is at night, and the lamps go out, the motorman may not find out that the trolley is off until the conductor gives him the signal to stop. The places where the pole is most apt to go off are at curves, crossings, and temporary turnouts. On the ordinary curve, such as is found where the car leaves the main line to go on to a branch line, there are three or four defects liable to lend an influence to the pole leaving the wire: in the first place, the swivel or pivot on the trolley stand may need greasing and refuse to act promptly even after the car has taken the switch several feet; in this case the wheel tries to follow the main line wire after the car has taken the switch leading into the curve, and the pole is just pulled off sideways. The trolley pole may be skewed around in the socket, or the harp may be crooked on the pole, or the harp may be twisted in itself; the result of any of these defects is to force the flange of the wheel over against the trolley wire, and if the trolley wire has the least bit of a kink in it, or if the flange of the trolley wheel is a little rough, the wheel will climb the wire and go off. At times, the frog, or overhead switch, may be out of order.

---

### FROGS.

**19. Relation Between Frog and Trolley.**—Fig. 21 shows how a frog is constructed and how the wires lead off from it. The car is supposed to move in the direction indi-

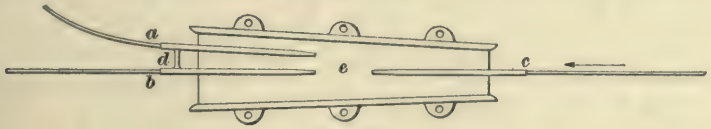



FIG. 21.

cated by the arrowhead; *c* is the main-line wire on the single-wire end of the frog, and *b* is a continuation of the main-line wire on the double-wire end of the frog; *a* is the

wire which follows the curve. There is a certain place *e* in the frog where there is no wire or ridge to guide the wheel; to keep the wheel from going off, the frog has along the two side edges a flange which also acts as a guide to the wheel when turning a curve. In Fig. 21, *d* is simply a rib intended to strengthen the two ridges cast in the frog. When a frog is in good order and the track switch is turned for the car to go straight ahead, the trolley should follow the main-line wire without any trouble; but if the frog, instead of being level, be tilted down on the side *a*, the wheel is apt to slide over that way and follow wire *a* while the car follows the track under the wire *b*. If the frog is crooked, so that *c* and *b* are not parts of a continuous straight line, the least bit of rough edge on either the flange of the wheel or on the flange of the frog will cause the wheel to ride the frog and go off. A kink in the wire just out from the frog will often throw the wheel off. Suppose, now, that the car is intended to take the curve; it must be borne in mind that the trolley wheel trails after the car and that the car will therefore always have started to change its course before the trolley wheel does. When the car turns into an open switch, it gets some distance around the curve before the trolley wheel reaches the line frog, and when it does get there the side pull on the

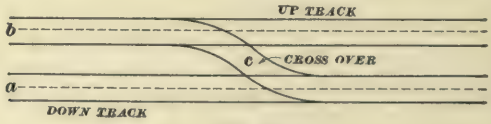



FIG. 22.

pole throws the wheel over to the proper side of the frog and the frog flange guides it on to the ridge into which wire *a* leads; crossings, especially steam-road crossings, are apt to cause a trolley to jump off unless the car is run over them slowly, for two reasons: in the case of the temporary cross-over, Fig. 22, which is nothing more than a temporary track laid to enable a car to get over to the oppositely running track, in order to avoid interference with men engaged in track repair work, sometimes there is a turnout wire

connecting the trolley wires over the two tracks and sometimes there is not. When there is no cross-over wire, the trolley, of course, is certain to come off, and the conductor must be on hand to pull it down as soon as the motorman gives the car a kick—that is, gives the car power enough to shoot it over to a point where the trolley pole can reach the other wire. In Fig. 22, *b* is one main line with its trolley wire; *a* is the main line with its trolley wire; and *c* is the cross-over without any trolley wire. When there is a wire running from one line to the other, the trolley is liable to jump in any way, because the temporary track is several inches above the regular rail, and in going to or off of this elevation the jolting of the truck is transmitted to the trolley stand and throws the pole off the wire. On steam crossings the effect of this jolting is intensified by the fact that the trolley wire is strung so high, in order to have it clear the smokestacks on engines and the heads of brakemen on freight trains, that the trolley pole, to reach the wire, must stand almost straight up, in which position the tension on the spring is very weak; the least jar at the right time will jump the pole off the wire, and it very seldom jumps back on again. In Fig. 23,

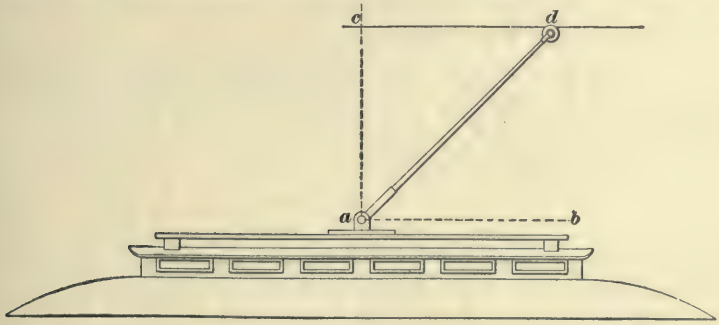



FIG. 23.

line *a b* is the line of the car roof; line *c d* is the line of the trolley wire; *a d* is the trolley pole. When the trolley pole is of the proper length and is bearing up against the wire, it should bear up with a force of about 15 pounds, and angle *c a d* should equal angle *d a b*; in other words, when

the pole stands out at an angle of 45°, it should press against the wire with a force of about 15 pounds. To illustrate: Take an ordinary spring balance and tie it to the trolley rope, as shown in Fig. 24. By pulling on the scale hook instead of on the rope, the scale will show exactly what pull is necessary to remove the wheel from the wire; this is exactly the force with which the wheel is pressed against the wire, and should be about 15 pounds. On some roads this pressure may be a little more or a little less. But 15 pounds will give good contact without excessive wear of the trolley wheel and wire.

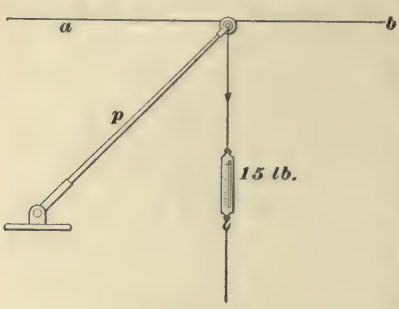


FIG. 24.

---

### CARE OF TROLLEY.

**20. Directions for Mounting and Oiling.**—Where a crew looks after its own car, the following points may be well taken: The wheel should be in the harp straight; the harp should be straight itself and straight on the pole; the pole should be straight and should be set in the socket so that, when the wheel is on the wire, the latter may rest on the bottom of the groove and run parallel to the flanges of the wheel. The crew should know how to adjust the tension on every trolley stand that they have to deal with. If they have a stand with features not included in the foregoing pages and they do not understand its actions and adjustments, they should, as a matter of common sense, ask somebody who does understand them. All moving parts should be kept well greased. The pivot around which the upper member turns on the lower member should be greased once a week, and in dusty weather twice a week or more; the pin around which the socket casting turns as a center should be oiled twice a week or more; the trolley wheel,

twice a day or more, the more the better; all nuts and spindles or sheaths which carry the compression or tension springs should be greased with stiff grease whenever their sluggish action shows that they need it. It is a common occurrence to walk into the repair shop of a large street-railway company and see several hundred trolley wheels in the scrap pile, with nothing the matter with them save that their bearings have been allowed to wear themselves oblong for want of a little oil at the right time. In oiling a wheel or any part of a base, care must be taken not to let the excess of oil run all over the car roof, for if the oiling is done as often as it ought to be, the roof of the car soon becomes a mess which is not only an intolerable sight, but is an unsafe footing for any one who may have occasion to work on top of the car. More short delays are due to inexcusable defects in the trolley and its rope and rigging than to any other cause; and a motorman or conductor who is fortunate enough to be promoted to the position of barn boss or shop inspector, should be qualified by his road experience to appreciate the necessity of keeping everything about a trolley pole and base in good shape.

### THE BRIDGE.

**21. Relation to Deck and Trolley Stand.** — The trolley bridge or board is simply a long board supported at

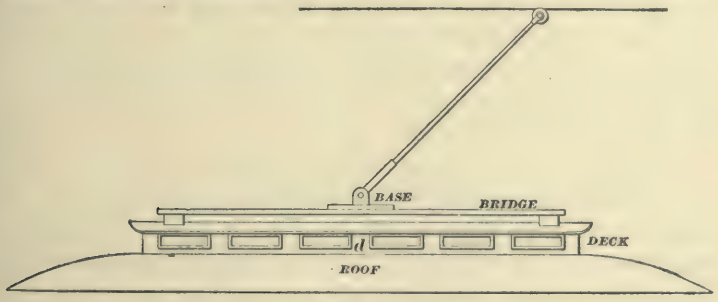



FIG. 25.

its ends on cross-pieces, as shown in Fig. 25, and serves the double purpose of providing a foundation to which the

trolley base can be fastened without boring holes in the car roof and at the same time acting as a spring to cushion the effect which the jolting of the car might have on the pole. Again, if, as sometimes does happen, the trolley base is torn from its seating, only the bridge is injured and the roof of the car is saved. The bridge is sometimes a plain board; in other cases it is composed of two pieces running the length of the deck, with cross-pieces at the end to hold them together. The deck is the raised part of the roof shown at *d* in Fig. 25, and the ventilating windows are often called deck sash. The lower member of the trolley stand is fastened to the bridge with lagscrews or bolts; bolts are better, because when lagscrews are used, the screw holes are ruined if the base happens to get wrenched. A lagscrew is a large wood screw with a coarse thread, and it is screwed into a hole somewhat smaller than the screw itself. A bolt is a machine screw with a nut on the threaded end of the shank; it is used in a hole somewhat larger than the shank of the bolt and in this case has the advantage that it affords a safe and simple means of attaching one end of the trunk wiring (Art. **22**) to the base of the trolley stand. Fig. 26 shows how this is done by means of the bolt and two iron washers *c*, *c*. If the end of the trunk wiring has no terminal on it, the end of the wire *N* is bent into an eye, placed over the bolt between the two washers and the nut screwed home.

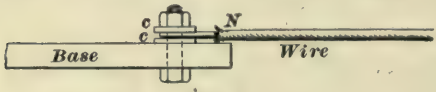


FIG. 26.

---

## TRUNK WIRING.

**22. General Explanation.**—The **trunk wiring** is that portion of the car wiring which leads the current from the trolley stand to the controlling devices underneath the car. The trunk wiring includes in its path the hood switches, sometimes called canopy switches, bonnet switches, overhead switches or main motor switches; these devices, their

principles of construction and operation will be taken up further on. The trunk wiring, properly speaking, also includes the fuse boxes and the lightning arresters, because these devices have to do with the main motor current—the total current which the car takes irrespective of whether the motors are in series or in parallel—and they will be talked of in an article devoted to them. Trunk wiring on a car gets its name in the same way and has the same meaning as the trunk line on a big railroad system; it is the main line, and carries all the current to the several branch circuits, just as the trunk line in a railway system carries passengers to all the branch lines. The trunk wiring begins at the trolley stand, Fig. 27, runs down the side of the deck to one bonnet, passes through the bonnet to the under side and takes

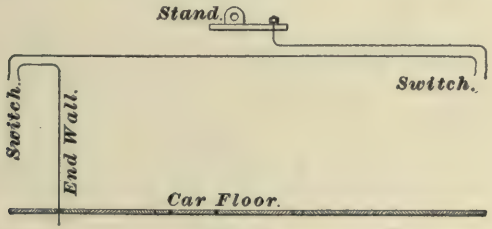



FIG. 27.

in one hood switch; it then passes out again to the roof of the bonnet, runs along the roof of the car alongside of the deck sash to the opposite end of the car, passes through that bonnet roof and takes in the second bonnet switch. In running this roof wire alongside of the deck sash, care must be taken that the wire will not interfere with the ventilators when it may be necessary to open them. After leaving the second switch the trunk wire passes out to the roof again, or it runs along the under side of the bonnet; in either case, its destination is the bulkhead on a closed car, or the corner post on an open car. The bulkhead is the end wall of the car and is composed of two thin walls, called linings, between which the doors slide when they open. It is between these linings that the trunk wiring passes down to the floor of the car and through a hole in the car floor to

the under side of the floor. Where this wire passes through the car floor—in fact where any wire passes through the car floor—it should be encased in rubber tubing to minimize the chances of the cars becoming charged. A car is said to be charged when it is in such a condition that a person stepping on it from the ground gets a shock. On an open car the wire from number two bonnet switch passes to one of the corner posts, down through a groove in the post to the floor, and through the floor to the under side.

**23. Running Wire in Molding.**—As a rule, the trunk wiring, the light wiring, the heater wiring, and the electric signal-bell wiring are put in at the factory where the car is built, but sometimes they are not; and there are cases where old horse cars and cable cars are converted into electric cars, and here there is no provision made for running the trunk wiring. No grooves are cut, no holes are bored, and in some cases there is no room to cut grooves or bore holes. Under such conditions it is customary to run the wires on the surface and to cover them with a molding. A molding is an ornamental strip of wood with a groove on the under side, and in this groove the wire runs. Fig. 28 shows the cross-section of a wire covered by a piece of molding; *a* is the surface on which the wire is run; *b* is the cross-section of the wire itself; and *c* is the molding, selected to match, as nearly as possible, the molding to be found in other parts of the car. When a molding is run on one side of the car to conceal a wire, a piece should be run on the other side in the same place, so that the public may be deceived as to its purpose.

FIG. 28.

**24. Details Relating to Trunk Wiring.**—One way of fastening one end of the trunk wiring to the trolley stand was shown in Fig. 26. It is well to make a few extra turns of the wire between the first cleat and the connection on the stand; this takes up the working motion of the wire, due to the jolting of the car, and makes the wire less apt to break off. Breaking off of the wire is more apt to occur on the

old-style wooden poles formerly used, because here it is necessary to run the wire the full length of the pole and to fasten it directly to the harp by means of a setscrew provided for that purpose; in this case, the wire gets all of the working up and down that the pole does, and breaking is a source of continual trouble. Where a wire passes through the car roof or bonnet roof, it is necessary to make some provision to prevent the water from leaking in; there are patented roof compounds for this purpose, but all that is really necessary is some stiff white lead, colored to match the roof color and served with a coat of thick varnish to give a glaze. Water will not work its way through this. Some parts of a car roof are made of a very thin wood, and a man walking around on top is liable to drop a wrench, a hammer, or trolley pole through it, or even to punch a hole through the roof with his heel; in such a case the hole may be repaired by tacking a piece of canvas over it and giving it a coat of white lead, varnish, and roof color. The trunk wiring is pretty well insulated by the wood through which it passes and is not very apt to give trouble from grounds and that sort of thing, although from rough handling and careless use of tools the wire is sometimes cut and nicked so badly that it burns off at the place where it is injured. Besides the ordinary care to be observed in placing the wire, the principal point is to make a safe and neat job. The roof wire should be well cleated down, and should not be run close enough to the deck sash to interfere with opening the ventilators.

**25. Size of Trunk Wiring.**—For 30-horsepower motors, the trunk wire should be a stranded cable equivalent to a No. 4 solid wire, and for two 50-horsepower motors a stranded cable equivalent to a No. 2 solid wire.

---

## CANOPY SWITCHES.

**26. General Description.**—The canopy switch, also called hood switch, bonnet switch, overhead switch, or main motor switch, is a device which is placed just above the

motorman's head on the under side of the bonnet. It is preferably placed a little in front of the motorman's position, so that he can look up and see it without turning his head around. The object of this main switch is to provide a certain and simple means of cutting off the main motor current, in case anything should happen to one of the controllers to make that device useless for throwing off the power. Sometimes a controller becomes grounded or short-circuited and the consequent flow of current through it is so great that the controller cannot break it; again, sometimes the trouble with the controller or some other device is such that it is very convenient to put the controller on the first or second notch and to start, run, and stop the car by means of the canopy switch. This switch is also used to kill the car; that is, to entirely cut the wiring and all the devices out of communication with the trolley wire when it is desired to inspect or work on any of the controlling devices. A motorman should never try to adjust a controller finger or to replace a broken motor brush without first throwing the canopy switch handle to the *off* position. The canopy switch, then, is an emergency switch, and on this account should be so placed that the motorman's most natural move will enable him to reach up and slap the switch off in case of necessity.

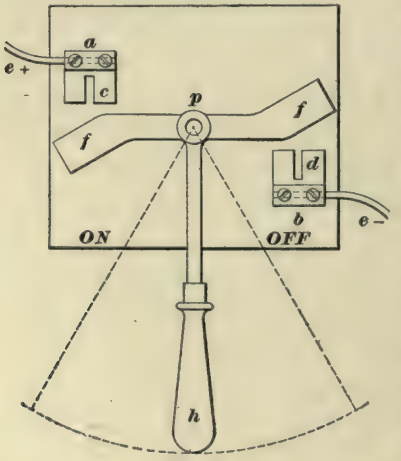


FIG. 29.

**27. Simple Switch.** Fig. 29 shows a simple form of switch, modifications of which are found in Figs. 30 to 37 inclusive. In Fig. 29, *a* and *b* are two connecting posts to receive the two wires *e*+ and *e*− leading into and out of the bonnet top; *c* and *d* are two spring jaws in metallic connection with posts *a* and *b*; *f f* is

a brass or copper switch blade turning on a pin or axle at *p* and provided with a wood or rubber handle *h*. In the position shown in the figure the handle is midway between the *on* and *off* position and no current can pass through the switch to the motors. If the handle be thrown to the dotted position marked *on*, the current enters at *c* +, goes through the switch blade *ff*, and leaves the switch at *e* —.

**28. The Westinghouse Switch.**—Fig. 30 shows the general appearance of the Westinghouse switch. The switch fixtures are mounted on a wooden base and over the whole is fitted the iron cover provided with four legs by means of

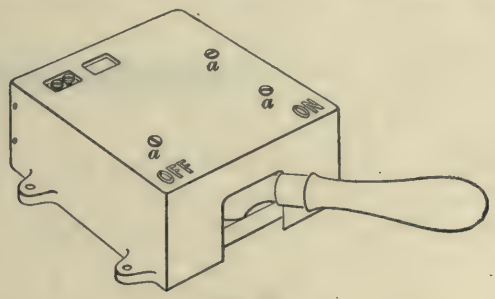



FIG. 30.

which the switch can be fastened to a wooden baseboard screwed to the under side of the bonnet. The *on* and *off* positions are marked on the iron cover, but to the old motorman they are of little use, because, from the fact that every company has a set way of putting up these switches, the men get so that they can tell whether a switch is on or off as far as they can see it. This switch cannot be gotten at inside very handily without taking it off the baseboard; the iron cover can then be taken off by taking out the three screws *a*, *a*, *a*, exposing the inside to view. These switches are sometimes called upon to break currents from 200 to 300 amperes, and some special provision must be made for doing this without too much arcing. On the Westinghouse canopy switch this is accomplished by having the switch blade break the current in two places at once; the two breaks being

separated from each other. Fig. 29 illustrates the idea, but does not illustrate it as carried out on the Westinghouse switch.

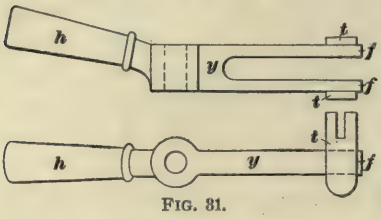


FIG. 31.

Figs. 31 and 32 show the construction of the Westinghouse switch blade and the path of the current when the switch is closed. In Fig. 31, *h* is the wood or rubber handle; *y* is the open-shaped piece of brass terminating in legs *f*, *f*, which receive the contact tips *t*, *t*. In Fig. 32, *e*+ is the wire leading into the switch, *e*− the wire leading out of it; *a* and *c* are spring blades set into brass lugs *l*, *l* separated from each other by the block or insulating material *d*. When the switch is closed, as shown in this figure, contact tips *t*, *t* press into blades *a*, *c*, and the path of the current through the switch is *e*+–*l*–*a*–*b*–*c*–*l*–*e*–.

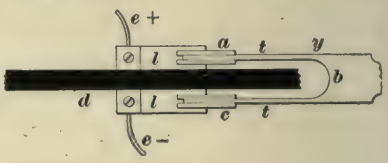


FIG. 32.

**29. The General-Electric Switch.**—Fig. 33 shows one type of General-Electric switch very much used; the interior of this switch is readily exposed to view by remov-

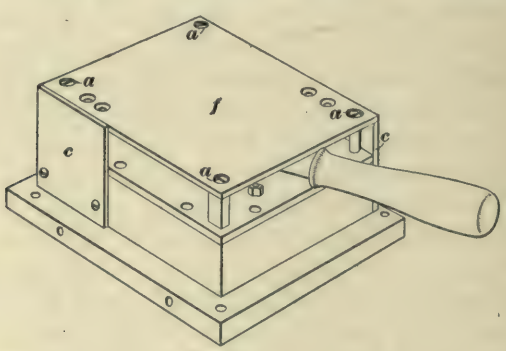


FIG. 33.

ing the four corner screws *a*, *a*, *a*, *a* which secure the fiber top piece *f*; the fiber corner pieces *c*, *c* prevent the flash

from licking out and disfiguring the car roof, should the switch get a little out of order. This switch is provided with a magnetic blow-out to extinguish the arc; on this account, the switch blade is made of iron, because it carries magnetic lines of force so much better than brass or copper.

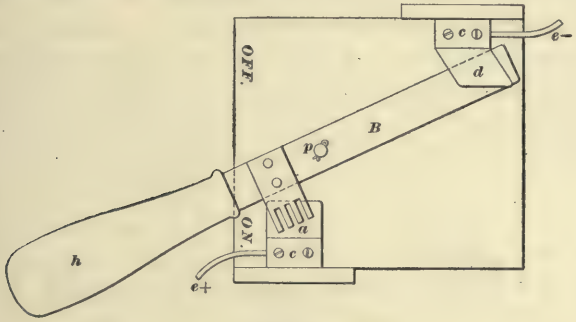



FIG. 34.

Fig. 34 gives the general idea of how the switch mountings appear when fiber top *f* is removed. *B* is the switch blade provided with handle *h*, working around a center; *c*, *c* are brass castings provided with holes to receive wires *e* + and *e* −, and also provided with spring blades *a*, *d*, into which the switch blade presses when the switch is on. When the switch is on, as shown in the figure, the path of the current is *e* + –*a*–*B*–*d*–*c*–*e* −.

**30.** Fig. 35 shows the principle upon which the blow-out coil works. *m* and *n* are two pieces of iron; *m* has a handle *h* and is movable round a center; *n* is stationary and has wound upon it a coil of wire which carries the main motor current; one end of this coil is attached to *n*, and the other end of the coil goes to one of the connecting posts *e* +; *m* is connected to the other binding post *e* −. In the figure the switch is shown closed; current is therefore passing through it, and the blow-out coil *s*

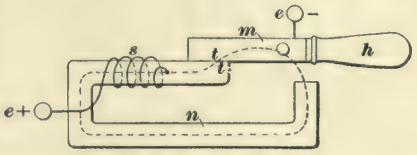



FIG. 35.

causes lines of force to pass through the path indicated by the dotted line. As soon as the switch is open, the circuit is broken at *t*, *t*, and the lines of force flowing across this point break the arc formed there. In this switch we have a condition which does not obtain in many electrical devices—the same piece of metal acting as both an electric and a magnetic conductor, for castings *m* and *n* not only carry all the current, but they carry also the magnetic lines of force due to the magnetizing coil *s*. When the switch is opened the magnetic and electric circuits are broken in the same place *t*, *t*. The principle upon which the arc is broken is this: the arc is repelled by the magnetic field, and in being repelled is made to stretch out so long that the voltage in use cannot support it across that distance; hence, the conclusion can be drawn that the higher the voltage in use the farther apart must *n* and *m* be drawn and the stronger must the magnetizing coil *s* be in order to break the arc. A switch adapted for use on a 500-volt circuit will not be reliable on a 1,000-volt circuit; nor will switches designed for motors of a certain horsepower work satisfactorily very long on a car equipped with motors of much greater horsepower, because the greater current causes so much more heating that the insulation on the magnetizing, or blow-out, coil gets roasted and becomes carbonized. When this happens, the current, instead of passing around the turns of wire and magnetizing the core, short-circuits through the burnt insulation, as shown in Fig. 36, and produces little or no magnetism. In

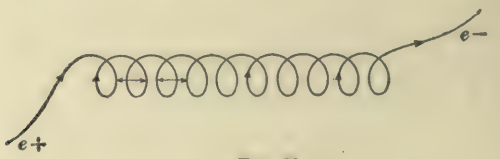



FIG. 36.

Fig. 36, the proper path for the current is round and round the turns of wire, but if the insulation gets roasted it becomes carbonized and instead of holding the turns of wire apart from each other, connects them together just the same

as if a copper nail were driven into the coil. The manner of short-circuiting is indicated by the double-headed arrows in Fig. 36. One of the first symptoms of a roasted blow-out coil is the failure of the switch to break the arc promptly, its effort to do so being accompanied by a kind of sputtering noise. If the switch is in good working order, the arc will be put out with no noise save a slight puff similar in sound to the noise made by the exhaust of a loaded steam engine.

**31. The Johnson Switch.**—Fig. 37 gives the style of switch made by the Johnson Company. It is circular in form and has two chambers, an upper and a lower, in which move two switch blades actuated by the same handle and arranged so as to break the circuit in two places. The case is made of cast iron, is lined with asbestos, and comprises two members *m* and *n*. The upper member *n* carries all of the working parts of the switch and can be removed from the lower member *m* by taking out four screws *o*, *o*, *o*, *o* on the side. When the upper member is lifted out, the switch blade that works in the lower member is exposed to view. Separating the upper chamber and switch from the lower chamber and its switch, is an asbestos-lined wooden partition which can be removed by taking out four more screws; this wooden partition serves also as a means of support for the bearing in which the shaft, carrying the two switch blades, and the handle turn. The switch is a cheap one, but does its work as well as any.

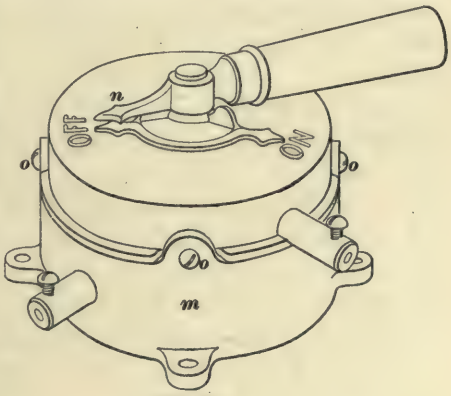


FIG. 37.

**32. General Remarks.**—There is one point above all others to bear in mind about canopy switches—and this is that when they are at the off position, it is impossible to get

a shock while working around the motors or controllers. Never go poking around any device on the car with a screwdriver or a pair of pliers, unless the canopy switch handle is at the off position; because the motor frames and controller backs are grounded, and if the tools connect either of these to any live part of the copper circuit, a short-circuit is certain to follow. It is an ordinary occurrence to see lying around street-railway repair shops, several hand bellows with their metal noses burnt off, as a result of sticking them into a live controller to blow the dust out of it. The canopy switches are generally connected in series, as shown in Fig. 38, and when so connected have the great advantage that the pulling of either switch breaks the main motor current, so that both the motorman and the conductor have the power of taking off the current in case of an accident. This is evidenced by the fact that very often when a crew goes in to take a car out of the house, the motorman, after putting in the switch on his own end of the car, calls to the conductor to put in the switch on the other end of the car; nor can he move the car until the conductor does so. However, on old styles of wiring it was sometimes the practice to put the canopy switches in multiple as shown in Fig. 39. Connected in this way the closing of either switch will start the car if either controller is on, and if both switches happen to get put on while the controller is off, it will be then necessary to pull both switches to break the circuit should the controller give out and fail to do its work. The series connection of Fig. 38 is simplest, safest, and best, and is the only method used at present on cars with up-to-date wiring.

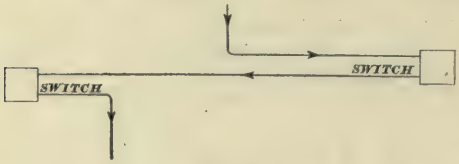



FIG. 38.

FIG. 39.

## FUSE BOXES.

**33. Use of Fuse Box.**—It has been seen that the hood switch is a safety device and that it has to be operated in case of an emergency by the motorman. The fuse box is also a safety device, but it is automatic in its action. If no fuse box be put on a car, the first time a ground occurs on a motor or any of its controlling devices, the rush of current is very great and the weakest part of the circuit, that is the part of least current-carrying capacity, will melt and blow up. This weak part may prove to be a loose connection in the car wiring or a bad contact in the controller; but it is more than likely that the weak spot will show up inside of a motor where the damage done costs most to repair. The idea of the fuse box is to provide for a weakest part in a circuit; in case of an abnormal rush of current the fuse in the fuse box should blow before anything else does. To make sure that it will do so, the fuse wire is made smaller than any wire to be found in any of the devices or car wiring that are called upon to carry the main motor current; the devices that carry the main motor current include the hood switches, fuse box, lightning arrester, motors, and controllers.

**34. Factors Determining Dimensions of Fuses.**—On a 30-horsepower equipment the armatures are generally wound with about a No. 9 B. & S. wire and the fields with about a No. 4 B. & S. or a No. 5 B. & S. wire, according to the nature of the work which the motor is called upon to do. The armature wire need be but one-half as large as the field wire, because it has to carry but one-half as much; the reason for this will be taken up in the lesson on motors. It would appear that in the selection of a fuse wire, it would only be necessary to choose a wire one size smaller than that in the field winding, but for several reasons, this is not so. The fuse wire must be a great deal smaller than the field wire. In the first place, the fuse wire is not embedded in insulation, and in the second place it is not running inside

of a closed motor where it could be acted upon by other heating influences than the actual carrying of the current. The result of its being outside, in an exposed place, is to give it plenty of air, hence facility to cool, so that for a given current its temperature will not rise as high as that of the wires inside of the motors. Another very strong influence which increases the current which a fuse can carry without melting is found in the copper lugs to which the ends of the fuse wire are attached. The fuse wires are, as a rule, comparatively short, so that the heat-conducting influence of the copper connecting lugs can be felt throughout the length of the fuse. Almost as fast as the heat is generated in the fuse wire it passes into the lugs and tries to raise their temperature; but it cannot, because the lugs have too much surface through which to radiate the heat imparted to them. If it were not for this heat-conducting power of copper, a short fuse would do just as well as a long one; but with full knowledge of the facts the fuse wire must be selected to allow for this modifying influence.

**35. Copper Fuses for 30-H.-P. Equipment.**—As a result of experience the copper wire used on a 30-horsepower equipment is about a No. 14 B. & S. A 30-horsepower motor running at full load takes a current of 45 amperes; two motors would therefore take a current of 90 amperes at 500 volts, and the fuse wire would have to stand this current continuously, if the motors always ran at full load. As a matter of fact, a 30-horsepower equipment running under the most usual conditions takes just about one-third of this current, or 30 amperes. Of course there are times and conditions when the car will take more than 90 amperes, but these do not last long, and if they do, it goes to prove that larger motors are needed for the work, for no 30-horsepower motor ever built will bear up under the strain of continual full load.

**36. Copper Fuses for 50-H.-P. Equipment.**—A 50-horsepower motor under full load at 500 volts calls for a

current of 75 amperes and a fuse wire proportionately larger than that used on a 30-horsepower equipment. The fuse wire should be about a No. 12 B. & S. gauge. The armature of a 50-horsepower street-car motor is wound with about a No. 7 B. & S. copper wire, and the field with about a No. 2 B. & S., so a No. 12 fuse wire gives plenty of margin. In the above it has been assumed that copper wire is to be used in all cases, because there is nothing special about it. It is cheaper than other special fuse wires and is just as reliable. No data can be given on fuse wires made of special metals, because their composition varies; but such fuse wire always comes on spools, unless already made up into fuses for some special fuse box, and in either case the current capacity of the wire is stamped on some conspicuous place.

**37. Determination of Motor Current.**—To determine what current any 500-volt motor calls for at full load, multiply the rating by $1\frac{1}{2}$. Thus, $1\frac{1}{2} \times 30 = 45$, the current taken by a 30-horsepower, 500-volt motor.

**38. The Westinghouse Fuse Box.**—Fig. 40 shows a perspective view of a Westinghouse car fuse box, and Figs. 41 and 42 give an idea of how the removable block which takes the fuse wire is constructed. Fig. 41 shows the fuse box with the lid open; *a*, *a* are the two castings which receive the two ends of the trunk wiring, through holes *d*, *d*, and they are provided with switch blades to take the tongues *t*, *t* in Fig. 42. The box, and also part *b* of the cover, is lined with asbestos so that the blowing of the fuse will not

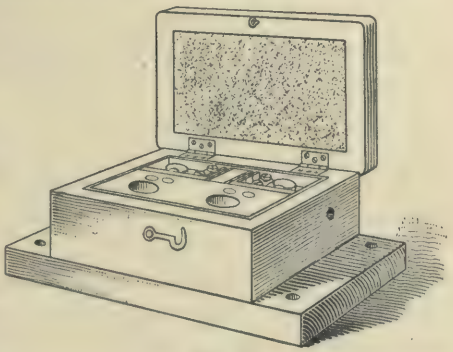


FIG. 40.

set the wooden case on fire. Holes *e*, *e* give the hot air and gases a chance to escape so that when a fuse blows, the lid of the box may not be blown off. Holes *k* are for the screws which hold the fuse box up against the platform stem under the car. Fig. 42 shows the removable block to which the fuse wire is attached as indicated by the dotted line; *t*, *t* are the two switch tongues which press into the spring jaws *a*, *a* of Fig. 41; *b*, *b* are the two thumbscrews by means of which the ends of the fuse wire are secured; *c*, *c* are two finger holes used to withdraw the block when it is necessary to put in a fuse. This fuse box has the great advantage that a fuse can be put in without any danger of getting a shock, even though the trolley pole may be left on and both canopy switches left in. To put a fuse in a Westinghouse fuse box, insert two fingers in finger holes *c*, *c*, Fig. 42, draw out the whole block and loosen up the thumbscrews *b*, *b*; next, make a hook in one end of the fuse wire, pass the hook under one thumbscrew and screw the thumbscrew down with the hand; do not screw it down with a pair of pliers, because the next man that gets the car may not have a pair of pliers and will be unable to get the nut loosened should he find it necessary to put in a fuse. The fuse wire is then passed all round the

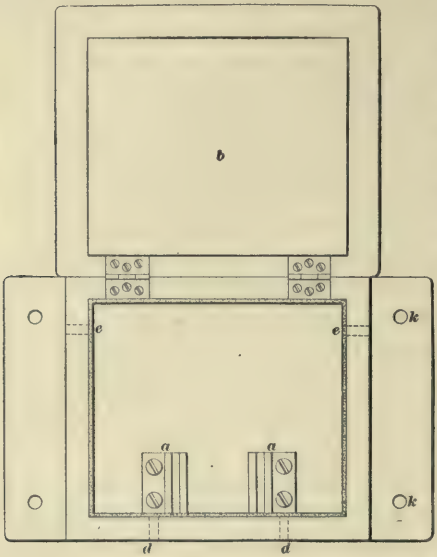


FIG. 41.

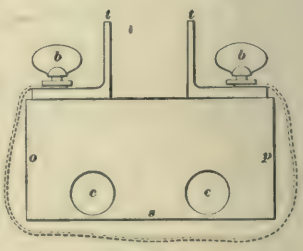


FIG. 42.

block, as shown by the dotted line in Fig. 42, and its end secured under the other screw. The figure shows the fuse wire to be loose, in order that it may be more easily seen; as a fact, the three sides *o*, *s*, *p* have a groove cut in them, and the wire is drawn down into this groove.

**39. The General-Electric Fuse Box.**—Figs. 43 and 44 show one form of General-Electric fuse very much used. In Fig. 43, holes *a*, *a* are two holes through which the trunk wire passes into and out of the fuse box; on each end of the box is a hole *b* through which a screwdriver may be put to loosen or tighten screws *b*, *b*, shown in Fig. 44 (*a*); *c* is a raw-hide flap which serves as a weather protector. A substantial lid is unnecessary on this fuse box, because the presence of a magnetic blow-out coil, *d*, Fig. 44 (*a*), allows very little arcing when a fuse blows.

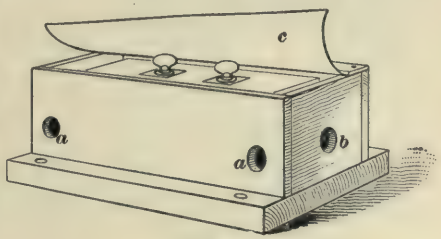


FIG. 43.

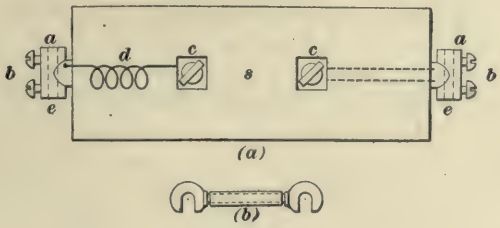


FIG. 44.

Fig. 44 (*a*) shows the member which fits into the wooden case shown in Fig. 43; *a*, *a* are two lugs provided with holes *c*, *c* to take the ends of the trunk wire, and screws *b*, *b* to secure the wire in place; *c*, *c* are also two lugs provided with thumb-screws to take such a special fuse wire as is shown in Fig. 44 (*b*). This special fuse with terminals and made of regular fuse wire is not necessary, as almost any fuse wire can be secured

under the thumbscrews, but it is a good thing because it makes sure that in a majority of cases the car is provided with a fuse of the proper size. On one side, *a* and *c* are connected directly together, but on the other side they are connected through coil *d*, which has an iron core so disposed as to throw a strong magnetic field across the space *s*, where the fuse blows. This fuse box does good work when in good order and will only give trouble when continuous abuse causes the blow-out coil to become short-circuited. To put a fuse in, it is only necessary to pull down the trolley or to throw off one of the hood switches and proceed as in the last case, excepting that there is no block to pull out.

**40. The Walker Fuse Box.**—Fig. 45 is a perspective view of the Walker Company's fuse box; *a* is an asbestos-lined iron case; *b*, *b* are two thumbscrews to clamp the ends

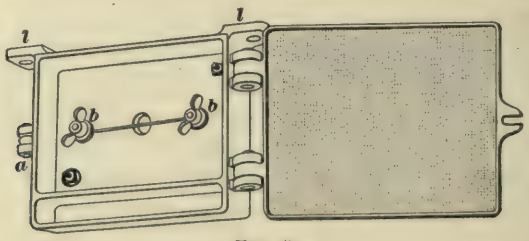



FIG. 45.

of an ordinary copper fuse to two lugs mounted on a slate base plate; these lugs pass completely through the slate base and the iron case, the case being cored out to allow it, to the rear of the fuse box, where they are drilled and tapped to act as connecting posts for the trunk wire. There is nothing special about the fuse box except the chamber provided to hold extra fuse wires, cut ready for use; also the legs *l*, *l* are so placed that the box must be screwed against the bottom of the car instead of on the side of the stem. A hood switch must be opened when fuses are replaced in a box of this type.

**41. The Johnson Fuse Box.**—Figs. 46 and 47 give an idea of a fuse box made by the Johnson Company. Fig. 46

is a perspective view, and Fig. 47 shows the means provided for extinguishing the arc caused by the blowing of the fuse. In Fig. 46, *a* is an asbestos-lined, cast-iron box to which is hinged the asbestos-lined lid *l*; *b*, *b* are two brass lugs, one end of which has thumbscrews for securing the fuse wire, and the other ends of which pass through the bottom of the iron case (in rubber bushings) and are there shaped to act as terminals to receive the two ends of the trunk wire; *f*, *f* are spring-actuated vulcabeston flappers which fly open when the fuse blows and thereby lengthen the arc until it breaks. In Fig. 47, *b*, *b* are the two castings to which the fuse wire is attached by means of thumbscrews *t*, *t*; *g* is a permanent asbestos-lined wooden partition; *f*, *f* are two vulcabeston flappers, the normal position of which is indicated by the dotted lines; a spring, not shown in the figure, holds them in this position unless a fuse is put in, when they must be in the full-line position. To put in a fuse, one end of the wire is secured under one of the thumbscrews *t*; the two flappers *f*, *f* are then pressed together against the partition *g*, the fuse wire brought over their tops taut and its end secured under the second binding screw. Whenever the fuse blows, the flappers fly open to the dotted position. This fuse box has no holes in the case for the escape of hot air and vapors. Two holes are provided in the lower part of terminal castings *b*, *b* to receive the trunk wire.

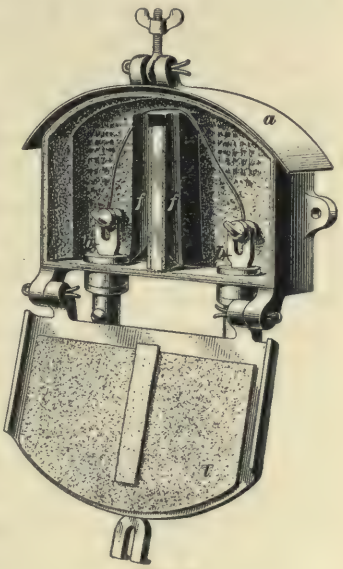


FIG. 46.

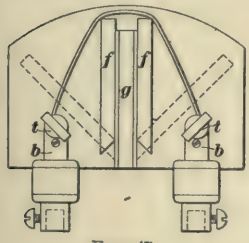


FIG. 47.

**42. General Remarks.**—It matters not what kind of a fuse box may be on a car, it is always best and safest to throw off one of the hood switches before trying to put in a fuse; it is then impossible to get a shock, impossible to get burned, and impossible for the car to start up unexpectedly. Any one of the above accidents can occur if the following conditions are obtained. To take them in order, to get a bad shock it is only necessary to leave the pole on, the hood switches in, and, standing on the ground, or resting the hand on any part of the truck or dash or gate irons, touch the trolley side of the fuse box; this is certain to happen on any of the above fuse boxes excepting the Westinghouse, and can happen on it if the operator is careless with his fingers when putting the block back into the box. To get a severe burn it is only necessary that there be a ground on the trunk wiring somewhere between the fuse box and the trolley binding post, or even the trolley binding post itself, in one of the controllers, or the magnetic blow-out coil if there is one. In Fig. 48 is given a diagram of a trunk wiring from the

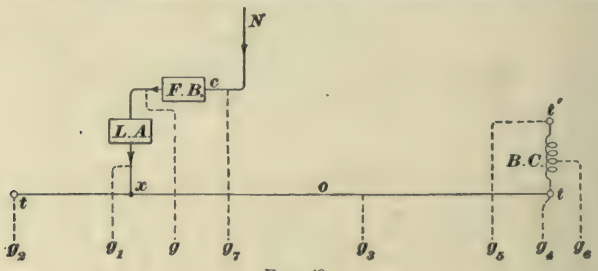



FIG. 48.

trolley side of the fuse box to the trolley post on one controller and to the negative side of the blow-out coil on the other controller. In Fig. 48, *Nc* is the wire which runs from the roof of the car down through the wall or post to the positive side of the fuse box *F.B.* *L.A.* is the lightning arrester; *t*, *t* the two controller trolley posts; and *t o t* the wire running the full length of the car to connect them together. *B.C.* is the blow-out coil, and *t'*, the connecting post or finger to which its negative end is attached; as long

as the circuit is all right and there is a fuse in *F. B.* the path of the current is *N–c–F. B.–L. A.* to the point *x*. From here the path depends upon which controller is being used; say the controller on the right is being used; then from *x* the path of the current is *x–o–t–B. C.–t'* on through the different parts of controller and motors to the ground. Suppose that the car, while moving along, suddenly develops a ground on the trunk wiring at any of the points indicated by the dotted lines leading to $g, g_1, g_2, g_3, g_4, \ldots g_7$, the car will give a kick or halt and the motorman will throw off his controller. The throwing off of the controller does no good, because if the ground occurs in any of the above indicated places or anywhere between *F. B.* and *t'*, the circuit to earth does not include the controller at all; i. e., the current gets to the earth through the fault before it gets to the controller, and the circuit-breaking part of the controller is cut out. Such a fault can very easily happen by the blow-out coil becoming grounded or by some wire under the car coming in contact with the brake rigging. In such a case the fuse generally blows before anything else can be done to open the circuit, and the motorman proceeds to put in another fuse. Now the ground which caused the fuse to blow in the first place will cause it to blow again; the consequence, then, of leaving the pole on and the hood switches in and trying to replace a fuse under any of the above conditions, is to have the fuse blow in the motorman's hand or face and burn him badly. Next, suppose after, that a fuse blows, the motorman fails to throw the controller to the off position before jumping off the car to put in a new fuse; as soon as the fuse makes contact at both ends, the car will start with a jump. Nine cases out of ten the motorman will get a shock before he gets both ends of the fuse wire in circuit, unless the fuse box is a Westinghouse, and the shock is apt to make him think a little. On an ordinary fuse box though, if the operator happens to secure the ground end of the fuse wire first he can get no shock until the remaining end touches the trolley thumbscrew; when this happens, the car starts at the same time that the motorman gets his shock—a very bad

combination—and the motorman is in bad shape to look after the car. The above is not an everyday occurrence, but inasmuch as it has happened, it might do so again.

**43. Twisted Fuses.**—It is the custom in some car houses to twist two or more small wires together to get a fuse wire of the right size; this is probably done under the impression that two small wires twisted together have twice the capacity of one small wire alone; but this impression is wrong; two small wires strung alongside of each other, as shown in Fig. 49, do have twice the current-carrying capacity of one wire alone; but when it comes to twisting them together their joint capacity depends on how tightly they are twisted. The tighter they are twisted, the larger is the diameter of the two together considered as one, and the greater is the capacity. Twisting fuse wire is uncertain and should be avoided.

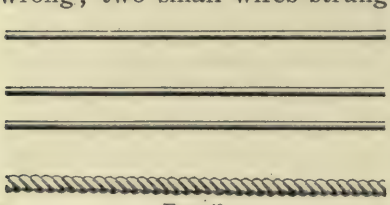


FIG. 49.

**44. Selection of Proper Size of Fuse.**—Many roads operate cars of different sizes equipped with motors of different output; and, in some cases, there does not seem to be any cast-iron rule as to what size or kind of fuse should be used on the different sorts of equipments. A motorman is given a bunch of fuses of a particular kind, perhaps without any instruction, and he uses them on whatever car he happens to be running—he may run several different kinds of motors in one day. If he puts in a fuse that is too small, it is not so bad; but if he should put in one much too large, all kinds of bad results are liable to happen, the principal of which are as follows: If a fuse is too large, it will fail to blow promptly when a motor or controller is in trouble, with the result that the controller itself blows up, frightens the passengers on the front seat so badly that they jump from the car before it stops and injure themselves, or fancy that

they injure themselves, enough to give the company a choice between a lawsuit and a settlement. The other less important bad effect of using a fuse that is too large is in the abuse which the car gets; if the fuse is of the right size, it will compel a motorman who does not know enough, or who does not take interest enough in the shop record of his car to do it anyhow, to run up steep grades and around sharp curves on the series-notches of the controller; if he tries to throw a loaded car into multiple under either of the above conditions the fuse should blow. Again, with a fuse of the proper size, as soon as one or more of the motor fields begin to roast, the car will begin to blow fuses at frequent intervals, and the motorman will turn her in for blowing plugs, as the men generally call the fuses. The barn men can then investigate the trouble and remove the weak fields before the other fields get weak, and perhaps save the armatures from throwing solder. A fuse might be called of the right size when under everyday traffic it has to be replaced about once a week. The reason it blows more readily at the end of a week than it does when it is first put in is that the heat oxidizes the copper—rusts it—and the jolting and jarring of the car, working this off, decreases the size of the wire so that it cannot carry as much current as it could when it was first put in.

**45. Substitutes for Fuses.**—It has very often happened that a motorman has found himself out on the road without a fuse but sadly in need of one. The ingenuity which some men have shown on such occasions is remarkable. A motorman has been known to cut a piece of wire out of a barbed wire fence to get a fuse to run home (8 miles) on; another borrowed a guitar string from a passenger musician; another wrapped his silver watch chain around the fuse-box thumbscrews and ran into the house on time; still another, who knew more than a motorman is supposed to know, opened the door of the controller on the rear end of the car, cut a piece of wire out of the No. 1 resistance lead, used it as a fuse and got home in good shape. That motorman is

now a road boss and makes 50 cents a day more than he did. This just goes to show what a thinking man can do when called upon to do it. If the men cited above had been unable to do as they did do, there is no doubt they would have done it some other way equally as good. Every motorman should think ahead and prepare himself for this particular emergency, because it happens so often; he must have it decided in his mind whether he will cut a piece of wire out of the heater circuit, light circuit, one of the controllers, or, at last one of the motor leads, leaving the car to run in on the remaining motor. If the motorman has not had advantages enough to think out these things for himself, let him get somebody that does know how to straighten him out. Of course a motorman is not advised to go promiscuously cutting wires about a car to get a fuse; the idea is that he should fortify himself with a knowledge as to which wires may be cut without further disabling the car.

**46. Location of Fuse Boxes.**—On single-ended cars the fuse box is always found on the same end as the controller; on cars having two controllers the end on which the fuse box is found is generally recognized as the front end.

---

### CONCLUSION.

**47.** Some roads prefer that a motorman know as little as possible outside of handling the brake and controllers. On large roads in crowded cities, where cars run under very short headway, this idea may be partially right looked at from the company's point of view, because here the quickest way to get a cripple out of the way is to let its follower push it; but in nine cases out of ten if the motorman knows enough to give his car some attention on his lay over, or to apply several quick and certain remedies for the most ordinary road troubles, both he and the company are better off, and in the long run his efforts are apt to be recognized and rewarded.

# CAR EQUIPMENT.

(PART 2.)

## THE LIGHTNING ARRESTER.

### TYPES OF LIGHTNING ARRESTERS.

#### THE GARTON ARRESTER.

**1. Description.**—Fig. 1 is given to show the construction of the *Garton arrester*, which is a satisfactory and reliable appliance made by an independent company. The discharge enters the arrester by the binding post *a*, to which is connected a wire leading from the trunk trolley wire; from connecting post *a*, the discharge passes across the non-inductive carbon resistance *b*, which is in multiple with the coil *f*, as shown in diagram, Fig. 2, to flexible cord *c*, to guide rod *d*, and armature *e*, which is normally in contact with, and resting upon, carbon *h*; thence across the air gap to lower carbon *j*, which is held in position by bracket *k*. This bracket also forms the ground connection through which the discharge reaches the earth, for a splice from the trunk ground wire runs into a connecting post forming the lower extension of the bracket. We have noted that the discharge takes its path through the non-inductive carbon resistance *b*, in multiple with the coil *f*; this carbon rod is of very high resistance, but a lightning discharge will readily



For notice of the copyright, see page immediately following the title page.

pass through a very high *ohmic* resistance in preference to passing through a few turns of wire constituting an *inductive* resistance; the trolley current, however, follows the arc set up by the lightning discharge across the air gap; this so called *normal* current prefers to pass through the turns of coil *f*, and, in doing so, causes this coil to become an electromagnet, which instantly draws up the iron core or armature *e*. The drawing up of this armature opens another air gap between the lower end of the armature and the upper carbon *h*, with the result that the arc

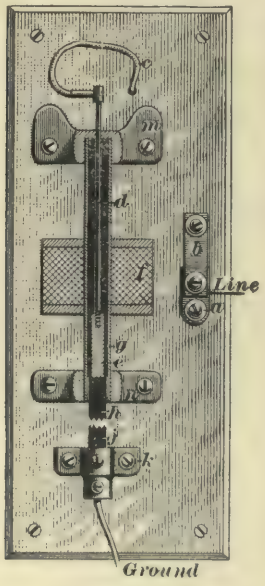



FIG. 1.

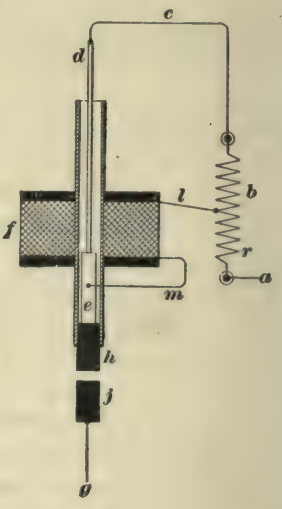


FIG. 2.

is made so long that the trolley voltage cannot support it. There are two other conditions present that tend to put out the arc; one condition is that since the arc is formed inside the air-tight tube *g*, there are no gases present to support combustion, and the arc tends to smother itself. An every-day illustration of this phenomenon is seen in the fact that an ordinary lamp flame may be extinguished by stopping up the vent holes in the burner. The other influence that tends to put out the arc lies in the fact that the arc takes

place in a magnetic field furnished by coil *f*. The three influences tending to disrupt the arc, then, are the lengthening of the air gap, the absence of gases to support combustion, and the presence of the magnetic field.

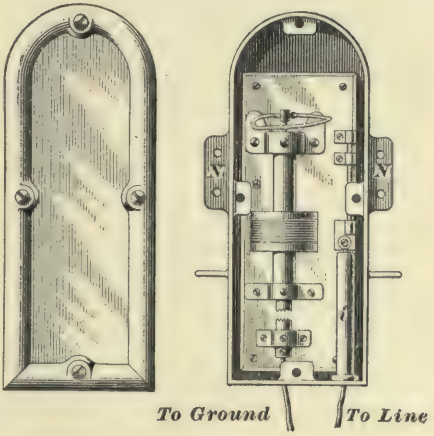



FIG. 3.

As soon as the arc is broken, the current, of course, ceases, the coil loses its ability to hold up its core, and the armature drops back to its normal position, resetting the arrester for the next discharge. To limit the value of the current that the trolley voltage can send through the arrester, it is customary to put a non-inductive resistance in series with coil *f*.

**2. Connections for Garton Arrester.**—Fig. 3 shows a Garton street-car arrester with the lid off, and Fig. 4 shows how such an arrester is connected up in conjunction with the kicking coil to be considered later. In Fig. 3, the wire marked *to line* is the splice *t* from the trunk trolley wire shown in Fig. 4. It passes into the arrester through the insulating sleeve *i*, Fig. 3, and connects to post *a*, shown in Fig. 2. The splice from the trunk ground wire connects to the post on the lower

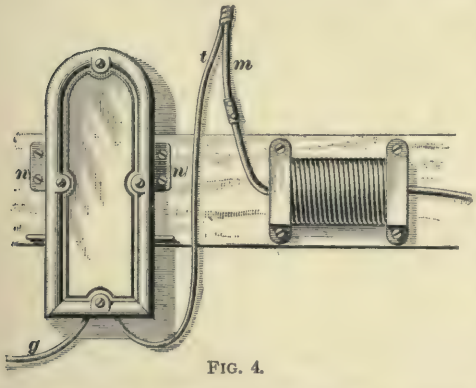



FIG. 4.

extension of bracket *k* in Fig. 1. In Fig. 4, *t* is the splice proper, from the trunk trolley wire. The main branch, or leg, *m*, goes to the kicking coil, and the other leg *t* goes to binding post *a* in Fig. 1.

**3. Remarks.**—This lightning arrester, like all others on the market, works fairly well, but sometimes it does not operate. As a rule, however, it gives good protection to apparatus. The air gaps should not be allowed to deteriorate, for as soon as the air gap between *h* and *j*, Fig. 1, gets thicker than the thinnest insulation on the motor, the motor is liable to be injured at any time. Occasionally, any arrester will become *grounded;* i. e., the air gap becomes short-circuited by foreign matter, or excessive flow of current fuses some metal part and portions of the molten metal run down and lodge in the air gap. This trouble is liable to happen to any arrester, and the first symptom of it is that the car blows fuses as fast as they can be put in. This happens with the controllers at the off-position, for it must be borne in mind that the arrester is in circuit ahead of the controllers. It should, however, be in circuit behind the fuse box, so that the fuse may blow when there is anything the matter with the arrester. As soon as a lightning arrester becomes short-circuited or grounded, the car cannot be operated until the ground wire leading into the arrester is cut or otherwise disconnected. The Garton arrester can be cut out of circuit by disconnecting or cutting either wire *t*, Fig. 4, or wire *g*. Of course, as soon as either of these wires is cut, the arrester ceases to be a protection, and must be repaired and reconnected as soon as practicable. From the fact that the core *c*, Fig. 1, falls back to its normal position from gravity alone, the arrester must occupy the vertical position shown in Figs. 3 and 4, or it will not work. The iron case is provided with two legs, shown at *N*, *N*, Fig. 3, and these legs are screwed to a board that is fastened underneath the car to one of the stems or sills. On some roads it is the rule to cut a hole in the car floor underneath a seat and set the arrester there—half of it above the floor and half of it beneath.

**4. The Discharge.**—In Fig. 2, the letters have the same significance as in Fig. 1. There are also four additional letters, *l*, *m*, *r*, *g*, representing, respectively, the positive and negative terminals of coil *f*, a small part of resistance *b*, and the ground wire. One lead *l* of coil *f* is connected to some part of *b*; the other lead *m* is connected to armature *e*; as soon as a lightning discharge enters at *a*, it takes the path *b–c–d–e–h–j* to the ground wire at *g*; but the trolley current that follows the discharge takes the path *r–l–f–m–e–h–j* to the ground at *g*. It is thus seen that there are two paths open for the discharge. The reason the lightning discharge will not pass through the path containing the coil is because of the coil's self-induction or spurious resistance; the reason the trolley current will not go through all of resistance *b*, is on account of its high resistance; a little of the current does go through *b*, but not much, as the resistance of *f* is so much lower. The resistance *r*, which is a part of *b*, limits the value of the trolley or normal current. In the actual arrester, connection *c* is made by means of the flexible cord shown in Fig. 1, and this cord also serves for connection *m*.

---

### THE AJAX LIGHTNING ARRESTER.

**5. Description.**—The *Ajax* is another type of arrester of which there are a great many in use. The street-car type of Ajax lightning arrester is shown in Fig. 5, where *A* is the frame proper, and *b* the rack for holding the fuses and the gravity ball; Fig. 6 shows the actual size of the fuses, of which there are eleven, and Fig. 7 is a diagrammatic sketch showing the path of the current when the arrester does its work.

The arrester consists of a frame or rack for holding a succession of fuses, so that one after the other may be brought into service by the action of the current as it destroys each fuse in turn. The fuse consists of two pieces of fine brass wire, each 3 inches long; about 1 inch of each piece is drawn into a glass capsule, as shown in Fig. 6, and secured to the ends of this air-tight capsule by means of an insulating wax.

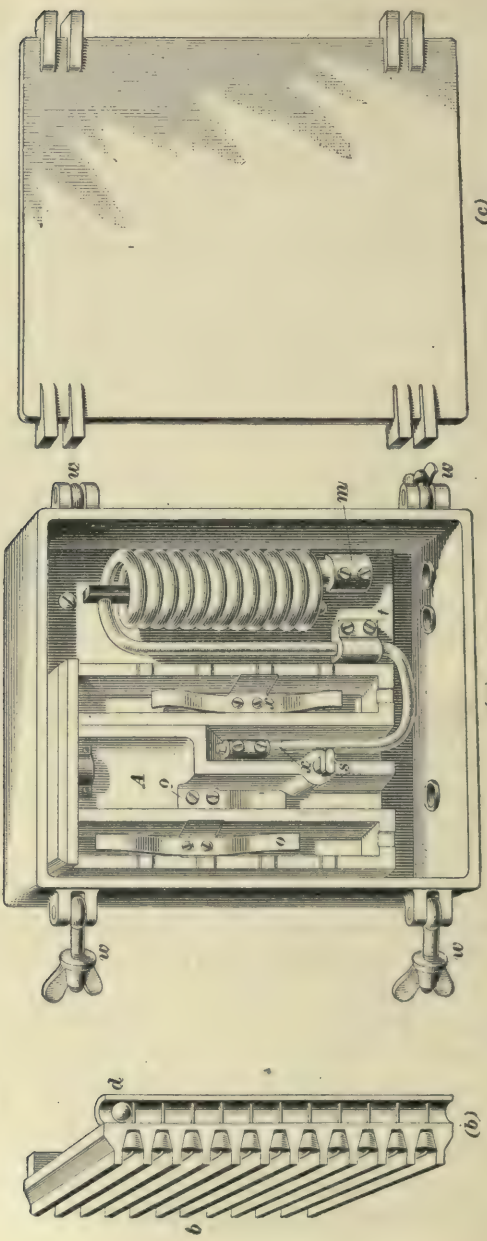



FIG. 5.

This 1-inch lap of the wires seems to be surface exposure enough for the air gap, which is only .002 inch thick; the air gap is but little more than the thickness of the two coats of insulating varnish into which the exposed ends of the fuse wires are dipped. The soft rubber plugs serve to hold the fuse in the corrugated cover or rack, and the bare ends of the wires project through the cover on one side and support the carbon ball, as shown at *d*, Figs. 5 and 7. Into the back of the cover *b*, Fig. 5 (*b*), are pressed two strips of metal; one a plain flat strip, to which one end of each fuse is connected by a long clamp; the other strip is **U** shaped or hollow, and into it the remaining ends of the fuse project, but do not make contact with it, except as the carbon ball completes the connection; that is to say, when the arrester is newly filled, the

FIG. 6.

ball rests on the end of one fuse and connects it to the **U**-shaped tube, while one end of all the other fuses sticks out into the tube without touching anything. One fuse is always ready for action; as soon as a discharge takes place, the fuse burns out in the capsule, softens on the end, and lets the carbon ball down to the end of the next fuse below, thereby resetting the arrester for the next discharge. In Fig. 5 (*b*), the carbon ball *d* is shown making contact between the top fuse and the **U**-shaped strip, which, when the cover is inserted in the porcelain back of the arrester, will make metallic connection with the line terminal through the flat spring provided for that purpose in the channel at the right in the porcelain. A similar spring is in the left channel to connect the flat strip in the cover to the ground terminal. The line and ground terminals, and the springs to which they connect, are seen at *o*, *o* and *x*, *x*, respectively, in Fig. 5 (*a*). The coil of white insulated wire in the right side of the case is the kicking coil; the connecting post marked *m* takes the wire leading to the controller-trunk trolley wire; the connecting post *t* takes the trunk wire from the fuse box.

and the post *o* takes the splice from the ground wire. There are three holes in the bottom of the case provided with hard-rubber bushings through which to bring up the respective wires to their posts. The lid, to the right, Fig. 5 (*c*), is made of cast iron, and is lined with asbestos; it is secured to the case proper by means of the eyebolts *w*, provided with wing nuts. The Ajax arrester may be placed under the car seat, or it may be fastened to a baseboard and hung to a sill or platform stem under the car.

**6. Principle of Ajax Arrester.**—Fig. 7 is a diagram that will make it easier to grasp the idea as to how the Ajax

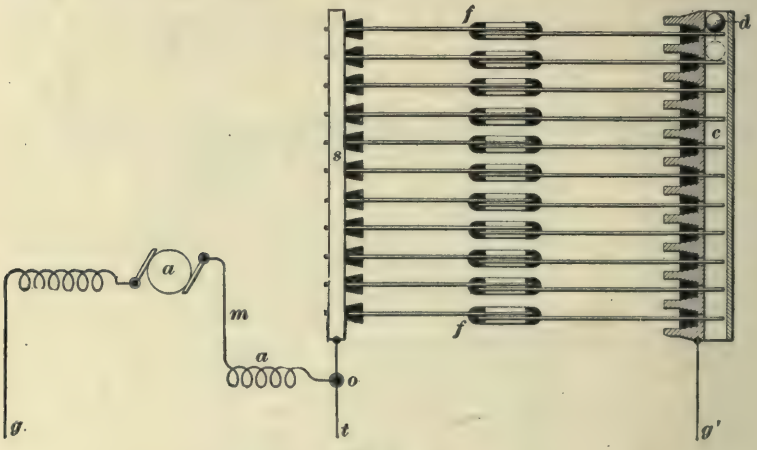



FIG. 7.

arrester is connected, and how it works when it is looking after a discharge; *f*, *f* are two glass capsules protecting the exposed ends of the two pieces of fuse wire; *c* is the metal tube into which one end of all the fuse wires runs but does not touch; *s* is the metal strip with which one end of all fuse wires makes contact; *c* is connected to the ground wire *g'*; *s* is connected to the wire coming directly from the fuse box; *a* is the kicking coil, one end of which is connected permanently to *s*. The other end *m* connects to the wire that runs from one controller to the other and thence to the motors. Under ordinary circumstances, the working current

from the fuse box enters the arrester at *o*, passes through the kicking coil *a*, and passes on through the motor parts to the ground at *g*. The working current cannot take the path *s–f–d–c–g'* because there is an air gap in the capsule *f*; the current would have to jump across from one wire to the other, and it cannot do that, for 500 volts pressure is not enough to urge it across. When, however, a lightning discharge, backed up by a pressure of several thousand or several million volts, enters at *o*, it jumps the air gap between the two pieces of fuse in the capsule, rather than instantly force its way through the self-induction offered by the kicking coil *a*, and motor windings *a*. The discharge then crosses on the carbon ball *d* to tube *c*, and passes off by way of the ground wire to the ground at *g'*. If the discharge itself does not destroy the fuse wire, the current that the trolley voltage urges over after it does, and the carbon ball, being deprived of its seat, drops down to the next fuse wire, as indicated by the dotted lines in Fig. 7, thus making the arrester ready for the next discharge.

**7. Remarks.**—The main precaution to observe in refilling an Ajax arrester with fuses is that the ends of the fuses be brought into the **U** tube so that they will support the carbon ball properly; if too short, or if bent down out of range of the ball, the ball has to drop twice as far to reset the arrester, and one fuse is lost. If this happens to the last, or bottom, fuse, the arrester will be of no protection at all. When refilling an arrester, each fuse should be carefully examined to insure that the two pieces of fuse wire do not touch each other inside of the capsule; if they do, the fuse will blow as soon as the ball touches it, because the trolley and the ground are brought directly together, thus producing a short circuit through the fuse. The Ajax, like the Garton, depends on gravity for its action, and must, therefore, be set in a vertical position. If screwed up against the bottom of the car floor, it cannot work, because the carbon ball cannot drop. After every thunder shower the arresters should be inspected, and, if necessary, refilled

with fuses. The probabilities are that several fuses will be found to have been destroyed, although there may not have been a single clap of thunder, showing that the arrester has been working. To make the arrester inactive, it is only necessary to give the thumbscrew *s*, Fig. 5 (*a*), a quarter of a turn, and lift the whole fuse frame out.

---

### THE WURTS NON-ARCING ARRESTER.

**8. Description.** — Figs. 8, 9, and 10 give a form of arrester made by the Westinghouse Company and known as the *Wurts non-arcing arrester*. This arrester has no movable parts, and is not adjustable nor has it any external means provided for putting out the arc caused by the trolley current following the discharge across the gap; in fact, there is no true gap in the ordinary sense of the word. The arrester consists of two blocks of metal, *b*, *b*, Fig. 10, screwed to a wooden block and separated from each other somewhat less than half an inch. The part of the wooden block that lies between the metal blocks is charred in grooves on the surface, so that the metal blocks or discharge points, instead of being separated by an air gap, are really connected by a very high-resistance (50,000 ohms) carbon conductor. The metal blocks are made of a special non-arcing metal, and the blocks must be a certain distance apart in order that the non-arcing property

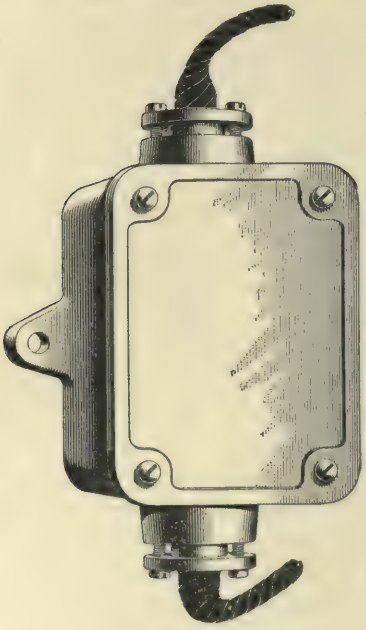


FIG. 8.

of the metal may be effective. This distance apart is so great as to render the device useless as an arrester, were it not for the charred surface between the blocks; the charred surface brings down the resistance of the gap so that a discharge will pass over it as readily as it will jump a very narrow air gap. Another block of wood, *c*, Fig. 9, fits down snugly over the metal blocks and their supporting wooden block, with which they are flush, leaving no room for the non-oxidizing vapors to discharge themselves, and thereby prevent the arc. The reason given for the destruction of the arc before it has a good chance to mature is as follows: As soon as the

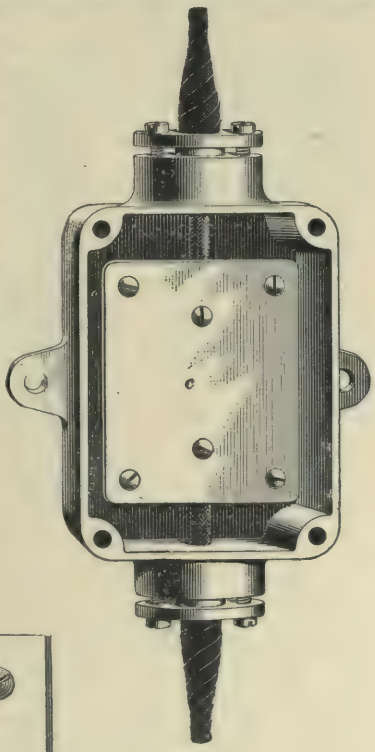



FIG. 9.

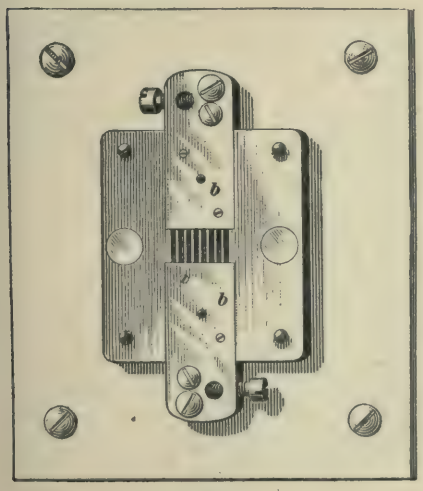



FIG. 10.

discharge passes, a small amount of arcing takes place and vaporizes a little of the non-arcing metal, and the non-conducting vapor confined in close quarters offers such a high resistance that the trolley voltage is unable to support an arc across it.

**9. Connections for the Wurts Arrester.**—Fig. 8 shows the arrester complete with the iron lid screwed in place; there are two flexible wire leads brought out of opposite ends of the arrester; one attaches to the trolley wire leading from the fuse box, the other to the ground wire running the full length of the car. Each of them attaches to one of the metal blocks *b*, *b*, Fig. 10, and, from the nature of the arrester, it does not matter which of them is made trolley and which ground; for this reason it is not deemed necessary to mark them.

**10. Remarks.**—The Westinghouse arrester is entirely unique, and there are a great many of them in use, both for car work and line work. Their strong point is their simplicity; it makes no difference in what position they are fastened, either in or under a car, and it makes no difference which lead is made trolley and which is made ground. If, through some violent discharge or defect in workmanship, the two blocks *b*, *b* should become short-circuited, it is only necessary to clip either of the flexible wires leading into it in order to cut the arrester out. Like all other arresters, it should be inspected occasionally to see if it is in good shape, for even though the arrester itself might be in perfect order, a loose or broken connection in any wire leading to or from it would render the device inoperative. To inspect the arrester, the iron lid must be removed, and also the wooden block *c*, Fig. 9. This can be done without taking the device from under the car.

---

### THE GENERAL-ELECTRIC ARRESTER.

**11. General Description.**—Figs. 11, 12, 13, and 14 show a type of arrester now manufactured by the General-Electric Company. Fig. 11 shows the general appearance of the arrester itself, and Fig. 12 shows the arrester encased in a common wooden box ready to be put on a car. Fig. 13 is the case proper provided with a magnetic blow-out coil *c*, a non-inductive resistance *r*, polar horns *h*, and knife blades *k*, *k*

to receive the spring clips $k'$, $k'$ of Fig. 14. The air gap, .025 inch wide, is shown at $a$, Fig. 14. When the porcelain lid $p$, Fig. 14, is turned over and set into the case proper, Fig. 13, spring clips $k'$, $k'$ engage knife blades $k$, $k$ and cut the air gap $a$ into circuit. It will be noticed that the air gap falls right in between the two polar horns, where there is a strong magnetic field, so that any arc that might occur at $a$ is quickly put out. The hasp $t$, Fig. 14, closes around pin $t'$, Fig. 13, and further secures the lid in place.

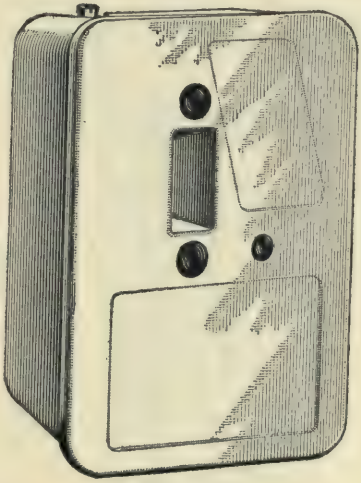


FIG. 11.

**12. Remarks.** — This type of arrester is designed for use on direct-current circuits up to 850 volts, and, therefore, covers all the demands of a street-railway circuit. The main body and lid of the arrester is of porcelain, and there are

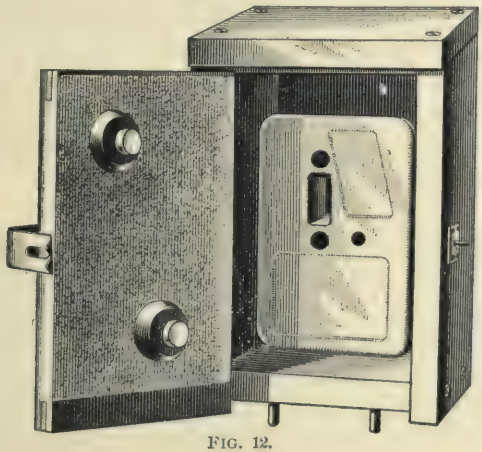


FIG. 12.

no moving parts; the discharge gap will pass a spark to earth when the potential on the line rises to 2,000 volts. The spark terminals or blocks are on the lid of the box, and are easy to get at for inspection and adjustment. In series with the spark gap is a low non-inductive resistance through which

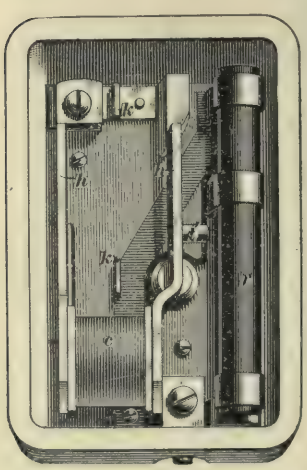


FIG. 13.

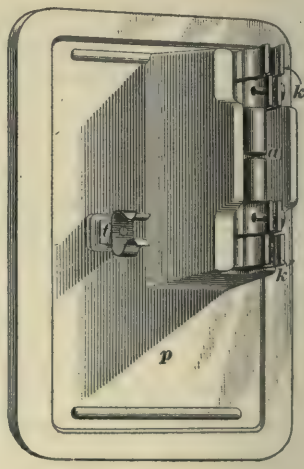



FIG. 14.

the line current passes when it follows the lightning discharge to the ground. As in the Garton arrester, this resistance limits the value of the normal current and reduces the tendency to burn away the spark terminals and increase the width of the spark gap. In order that the blow-out coil shall offer no inductive resistance to the lightning discharge, the coil is put in multiple with a part of resistance *r*.

**13. Earlier Type of General-Electric Arrester.**— Fig. 15 shows an earlier type of the General-Electric Company's arrester, of which there are a great many in use. Fig. 16 shows the internal connections. In Fig. 16, *a*, *b*, and *c* are brass connecting posts; the trunk trolley wire goes into *b*, the splice to the controller trolley wire into *c*, and the ground wire into *a*; *f* is a strip of copper that connects terminal *b*

with the casting *h*, and with *c*, which is one end of the very coarse wire coil *d*; the other end of *d* connects to the terminal *c*, into which the motor wire runs; *i* is an oblong brass casting insulated both from *h* and the ground post *a*; there are two air gaps *s*, *s*, one between *i* and *h*, the other between *i* and *a*. The main motor current passes through coil *d* all the time, taking the path *t–b–f–c–d–c–m*. As soon as lightning strikes the arrester, it takes the non-inductive path *t–b–f–h–s–i–s–a–g* to the ground, rather than pass through coil *d*. The trolley current follows it over the gaps and would soon burn the spark points up, were it not that the arc is blown out by the magnetism furnished by coil *d*. As soon as the discharge passes, a large part of the current is diverted through the air-gap circuit *t–b–f–h–s–i–s–a–g* to the earth, but enough passes through the low-resistance coil to put out the arc. To intensify the effect, coil *d* has an iron core and iron pole pieces extending above and below gaps *s*, *s*. The location of these pole pieces is indicated by the dotted outline.

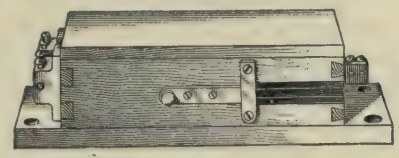


FIG. 15.

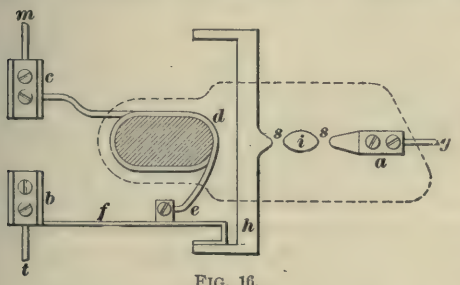



FIG. 16.

## GENERAL REMARKS ON LIGHTNING ARRESTERS.

**14. Inspection.**—All lightning arresters, of whatever make, should be inspected after each thunder shower, for even if the arresters themselves are in good shape there may be some loose or broken connection in a wire leading to or from the arrester. If the ground wire is broken or disconnected, the arrester might just as well not be on the car at all.

The principal point to be observed about an arrester is that the air gap should be thinner than any of the insulation to be found on the motors or the controllers; if inspection is neglected, and, through burning and jolting of the car, the air gap is allowed to get thicker than the insulation it is to protect, the lightning will jump through the insulation, rather than jump across the air gap; hence the importance of regularly inspecting an arrester and adjusting the width of the air gap if necessary.

**15. Installation.**—Since, as we have learned, lightning is the sworn enemy of self-induction, it is important that all wires running to and from the arrester should be as straight as possible, because a straight wire has less self-induction than a crooked one.

All arresters having movable parts dependent on gravity for action, such as the Ajax and the Garton, should be placed in a vertical position, otherwise gravity cannot do its work. Care should be taken in connecting up an arrester to see that the trolley wire, motor wire, and ground wire are placed in the proper connecting posts. On the Westinghouse arrester no mistake can be made, because there are only two wires and it makes no difference which of these goes to the ground, the remaining wire being spliced to the wire coming from the fuse box.

**16. Connections for Westinghouse Arrester.**—Fig. 17 shows how a Westinghouse arrester is spliced into circuit.

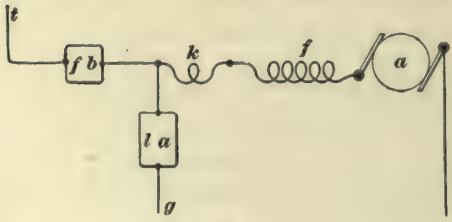


FIG. 17.

*t* is the wire from No. 2 hood switch; *f b* is the fuse box; *l a* the arrester; *f* and *a*, the motor field and armature, respectively; *k*, the kicking coil; and *g*, the arrester ground connection. Carefully note the position of the kicking coil,

**17. Connections for General-Electric Arrester.**—Fig. 18 is a diagram of the General-Electric Company's latest type of magnetic blow-out arrester, and also shows the manner of connecting the arrester to the wire coming out of the negative side of the fuse box; $z\,l$ is a carbon resistance, divided into two parts, $r'$ and $r$; part $r'$ is in multiple with the blow-out coil $d$, and part $r$ is in series with both and serves to limit the value of the trolley current that always follows the discharge across the air gap $a$. One end of the blow-out coil $d$ is attached to one side of the air gap and to one end of the carbon resistance at $z$; the other end of the coil is attached to the resistance at point $p$, dividing the resistance into two parts $r$ and $r'$. The trolley connection enters at the upper left-hand side of the case and connects to one side of the air gap; the figure indicates the connections to the air gap as permanent, but this is done for simplicity only; as a matter of fact, the air gap is not in the device at all until the porcelain block shown in Fig. 14 is put in place. In the figure, $t$ is the trolley wire leading *to* the fuse box; $t'$, the wire leading *from* the fuse box; $k$ is the kicking coil; $f$ and $a$, the motor field and armature, respectively; $g$, the motor ground, and $g'$ the lightning-arrester ground, running from the main ground wire to a post in the lower right-hand end of the box. As far as can be seen a confusion of the trolley and ground connections on the device would make no more difference than it does on the Westinghouse arrester, as the main trolley current does not pass through the device except when a discharge passes. Ordinarily, the path of the current is $t$–$t'$-$k$–$f$–$a$ and to the ground at $g$; as soon as lightning strikes, it takes the path $t$–$t'$-$t''$–$a$–$n$–$z$–$p$–$r$–$l$, and to

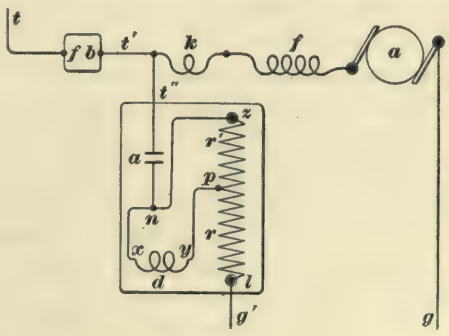



FIG. 18.

the ground at $g'$; on reaching point $n$, it has two ways of getting to point $p$—through the carbon resistance by way of path $n$–$z$–$p$, and through the blow-out coil by way of path $n$–$x$–$d$–$y$–$p$; since the blow-out coil acts as a kicking coil, the discharge prefers to take the carbon non-inductive path in multiple with it. Also, since the trolley current that follows the discharge over has more time to decide which path it will take, and, since it has not such on enormous voltage behind it, it passes through the very low resistance coil rather than go through the higher resistance $r'$. In passing through the coil, the pole pieces $h$, $h$, Fig. 13, throw a strong magnetic field across the gap $a$; the arc is put out and the arrester is ready for the next discharge. This arrester seems to be giving satisfaction in spite of the many predictions that the heat of the arc would break the porcelain case. Fig. 18 shows how the leads come out of the porcelain case, one at the top and one at the bottom, but when an additional wooden box, such as that shown in Fig. 12, is used, both leads are brought out at the bottom of the box. This arrester has no movable parts depending on gravity for their action, and, therefore, it makes no difference in what position it is set up. As in other cases all wires should be straight.

**18. Connections for Early Type of General-Electric Arrester.**—The earlier type of General-Electric Company's arrester shown diagrammatically in Fig. 16 is connected up as shown in Fig. 19; in this figure, the letters stand for the same parts as in Fig. 16. This arrester differs from the preceding ones in that the main motor current passes through it all the time. The action of the arrester has been considered in connection with Fig. 16, but it might be added that, since the putting out of the arc depends on enough of

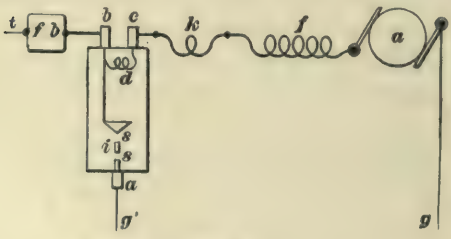



FIG. 19.

the current passing through coil *d* to provide enough magnetism to be effective as a blow-out, the arc will only be extinguished when the coil connections are in good shape. A carbonized coil or a loose connection will seriously impair the working of the device, and under this condition the spark blocks will be burned so badly as to fuse together, thereby grounding the line and making it necessary to disconnect the arrester ground wire. In some cases the spark points will burn off, thereby so much increasing the width of the air gaps as to render the device useless as a protector. The idea might be advanced that, since the arc-extinguishing power of the arrester depends upon a trolley current flowing through coil *d*, the arrester would be burned up should it be struck by lightning when the power is off. This cannot be so, because it is the trolley current that follows the discharge that does the burning, and if the power is off, the trolley current cannot follow. A very serious mistake can be made in connecting up this arrester to the trolley wire, as there are three connections to make. To avoid any such mistakes the arrester's wooden case is generally stamped as shown in Fig. 20; the wire from the fuse box goes into *b*; the wire to the motors into *c*, and the ground wire into the post *g* on the opposite end of the box. If by mistake the trolley and ground wires are confused and exchange places, it will be impossible to start the car, because there is an open circuit across the air gap *s s*, and even were the circuit closed here (supposedly), the ground would cut out the motors so that they would get no current to start the car. If the motor wire and the ground wire are confused, the same short circuit occurs, with the additional disadvantage that the blow coil is in circuit and its cotton insulation is liable to be roasted. No current can get to the motors, because it cannot jump the air gaps *s*, *s*. A confusion of the trolley and motor wires will have no

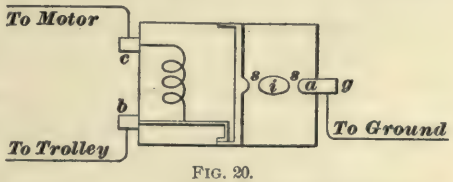


FIG. 20.

effect on the action of the car, and they might be confused for months without its being found out unless the car should be struck by lightning, and thereby give rise to an investigation; but the effect of putting the trolley wire into *a* and the motor wire into *b* is to seriously impair the working ability of the arrester. When properly connected, as shown in Figs. 19 and 20, the blow-out coil *d* acts also as a kicking coil and diverts the lightning from the motor circuit; the discharge has a straight, short, non-inductive path from *b* to *g* across the air gaps *s*, *s*. The effect of having *b* and *c* exchange places is to put the blow coil directly in the path through which the lightning discharge must pass to save the motors; in other words, such a connection places an inductive resistance in series with the air gaps, when it should be in series with the motors as shown in Fig. 19. In two cases on record where the trolley wire and motor wire were interchanged, the discharge, rather than pass into coil *d*, jumped over from *c* to *b* and then proceeded on its way across the air gap to the ground.

**19. Connections for Ajax Arrester.**—Fig. 21 is a diagrammatic sketch of the Ajax arrester shown in Fig. 5. The fuse capsule is not shown, but the air gap is indicated at *s*. This arrester, like the one just considered in Art. **18,** has three connecting parts, and, unless a person understands the arrester, there is apt to be a confusion of wires, and with results very much akin to those discussed in the preceding article. The trolley, motor, and ground-wire posts are, respectively, *t'*, *m*, and *e*, and *k* is the kicking coil. The trolley post is the middle one, and any current arriving at that post

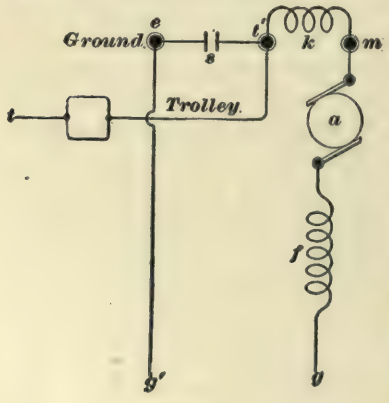


FIG. 21.

has two paths to the ground presented to it—one path to the right through the motor circuit, and one to the left through the air gap. The working current cannot ordinarily go to the left because it cannot cross the air gap; lightning does not go to the right because it is combatted by the kicking coil. The motor circuit then is in series with and is protected by the kicking coil. If the ground wire should happen to exchange places with the motor circuit wire, a short circuit follows and the main motor fuse blows. The effect of having the trolley wire and the motor wire exchange places is the same as in the case of the arrester considered in Art. **18,** namely, the lightning discharge must pass through the kicking coil to reach the air gap, and, inasmuch as it will refuse to do so, the device loses its value as an arrester. To avoid any confusion in connections, the posts on this arrester are very clearly marked *line*, *motor*, and *ground.* The Garton arrester has but two connecting posts, and, like all arresters of this class, very little damage can result from the confusing of the leads, provided the kicking coil is always spliced to the lead that is assumed to be the trolley.

**20. Use of Kicking Coils.**—The kicking coil is a device very generally used, and consists of a few turns of coarse wire wound upon a wooden core simply to keep the

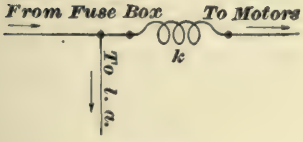



FIG. 22.

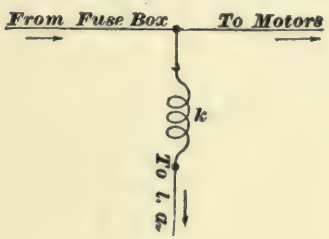



FIG. 23.

turns in place. In the absence of any regularly adopted type of kicking coil, it is customary to make the wire leading from the fuse box a little longer than is necessary and to

coil it into a spiral just beyond the point where the arrester taps on. Care must be taken, however, that this coil is put in series with the motors and not in series with the arrester air gap. Fig. 22 shows how the coil should be cut in, and Fig. 23 shows how it should not be cut in. On the Garton, and Westinghouse, and the later type of General-Electric Company's arrester, the kicking coil is an extra device, but on the Ajax and the earlier General-Electric Company's arrester the coil is self-contained in the arrester, thereby making three connecting posts necessary.

**21. Protection Afforded by Arresters.**—Lightning arresters in many cases do a great deal of good; in other cases, they are, like everything else in the path of lightning, useless. When, for inductive or other reasons, a consideration of which would be out of place in this paper, the potential of the line rises to several thousand volts, the arrester, if in good order, will pass a spark and in so doing lower the line pressure and relieve the tension; but if one of those bolts of lightning, such as jump a quarter of a mile through air to splinter a tree or to open the side of a house, strike a car, the arrester is of very little use and only invites its own destruction along with whatever else may be destroyed. Now the field and armature insulation on street-car motors is required to stand a pressure of only 2,000 volts in the test it gets before leaving the factory. It is evident, then, that the air gap on an arrester should be so adjusted that it will pass a spark before the line reaches this potential, because after an equipment has been run awhile, and then allowed to stand in the house, its insulation is not as good as when it was new. It would not be a hard task to make a very sensitive lightning arrester if the lightning were the only foe to contend with; but the trolley current that follows the lightning over must be looked after, or it will burn the arrester so as to make it unfit for the next discharge, and this would be a very bad state of affairs, because several discharges often follow one another at intervals of a second or two. Again, on a line several miles long, the same discharge has been known

to injure cars running at opposite ends of the line; this accounts for the fact that cars are sometimes struck by lightning when no thunder is heard and no flash seen. Certain conditions raise the potential of the whole line and the most sensitive arrester or the most defective insulation gets the first discharge. It has generally been found impracticable to work an arrester on a thinner air gap than .025 of an inch; this is thin enough for ample protection. Arresters seem to work on a gap as thick as one-sixteenth of an inch, but this is not safe. The trolley pressure, 500 volts, will not jump .025 of an inch, but a pressure of 1,500 or 2,000 volts will pass a spark, and the trolley voltage uses the spark and its heated path as a bridge on which to pass over the air gap to the ground.

---

### CHARGED POLES.

**22.** Every motorman with an experience on an overhead-trolley line knows or thinks he knows more or less about *charged poles*. A charged pole is a live pole, one that will give you a shock if you stand on the ground and touch it, and many road men are accustomed to say that the pole is grounded, or that it is alive or charged because it is grounded. This is an entirely wrong idea; the pole is not grounded, and it is alive, or charged, just from the fact that it is not grounded. Lightning is probably the cause of some "grounded" poles; it breaks down the insulation of some feeder that is off the insulator and rests on the iron cross-arm. The trolley voltage gradually works a leakage current through the defect and in course of time destroys the insulation, so that the feeder is in metallic contact with the cross-arm. The base of the pole being deeply buried in the moist earth, a current passes through this damp earth to the rail and soon dries the moisture immediately around the pole by decomposing into gases the water that causes the moisture. In course of time a layer of dry earth encases the pole; dry earth being a very poor conductor of electricity, the pole becomes practically insulated from the earth and the voltage finds no way of

sending any appreciable current to the rail. If, at this stage, any one standing on the ground touches the pole, current passes through the body to the damp earth and thence to the rail. If the live pole stands on a corner and if, as is often the case, it is fastened to several other poles with iron guy wires, all of them become alive, and contact with them will give a person a severe shock or will kill a horse. When the earth is damp, steam and smoke may often be seen rising from around the base of a live pole. The steam comes from the moisture, which is vaporized and, to some extent, decomposed by the current; the smoke is due to the action of the current on the japan or tar with which the pole is painted. A feeder that has slipped off from an insulator is often swayed to and fro by the wind and rubs against the cross-arm. The constant chafing wears off the insulation, letting the bare wire down on the cross-arm, and making the pole alive; if the ground is dry, there will be no evidence of the charged condition of the pole until some one resting a hand on it gets a shock. A shock is possible when the earth is dry, because the portion of earth between the person's feet and the base of the pole is in multiple with the person's whole body and the current divides between the human body and the span of earth that lies between the feet and the base of the pole. It is evident, then, that a great deal of personal discomfort can lurk in a line pole that may be apparently harmless. Thus, it can be seen that the habit some people have of resting one hand on a pole is a very bad habit. If a motorman in the course of his daily duty should notice a pole smoking at the base, or a feeder off its insulator, or a guy wire in contact with the trolley wire, he should immediately report the conditions to an inspector or to some one in a position to have the matter attended to promptly. This little consideration of charged poles can hardly be included under the heading of lightning arresters, but both live in a dangerous atmosphere, and, almost anywhere in these Papers, the student must prepare himself to meet short talks on facts and features having to do with personal safety.

# RESISTANCE COILS.

## GENERAL CONSIDERATIONS.

**23. Reasons for Use of Resistance Coils.**—The resistance coil, sometimes called starting coil, is a device used to limit the value of the current at starting; this permits the car to be started smoothly without jerking, and protects the motors from the undue strain that would result from an excessive current. In connection with the controller, the starting coil is used to regulate the speed of the car after it has started. It must be borne in mind that, wherever there is resistance in a circuit through which a current flows, there is heat, and wherever there is heat there is a loss of energy (energy is the capacity for doing work) that cannot be converted into useful work. If it were not for this fact, the motors themselves could be so wound that they would have resistance enough to hold the current down to a safe value at starting; but then this resistance would, to a greater or less degree, be in circuit all the time and there would be a constant and excessive loss of energy due to heating. A great many motormen are in a position to declare that certain cars run slower after they become well heated than they do when they make their early trips. This effect is very noticeable on heavy cars equipped with old-style motors. In order, then, that the equipment shall waste as little power as possible, the resistance of the motors is made very low; on account of this very low resistance, the line pressure of 500 volts would send through the motors an enormous starting current that would not only start the car with a jerk, but would strain the motors and gearing; to do away with these two bad effects, the starting coil is used. It is true that the starting coil gets very hot and its heat represents just so much lost energy, but, proportionally, it does not get nearly as hot as a high-resistance motor, because it is exposed to the air and is not in a closed frame as the parts of a motor are. Again, the

starting coil is intended to be used only on the starting notches of the controller; when the running notches are used the coil is entirely cut out and cannot, therefore, have any effect upon the maximum speed of the car.

**24. Running Cars on Resistance Notches.**—It is a very bad practice to run a car for any length of time on a resistance notch. There are three reasons for this: in the first place, it is not an economical notch to run on, because the heating of the coil means just so much energy wasted; in the second place, the coil is designed for the temporary use of starting only, and when continuously used for slow running it gets so hot that the insulation is destroyed, the coil short-circuited, and the car made to start with a jerk; in the third place, accordingly as one starting notch or the other is used for running purposes, one part or the other of the coil will be abnormally heated and there will be certain notches between which the car will jump badly. This is because the material of which the resistance is made (usually band iron) increases its resistance very rapidly as it gets hotter. Ordinary starting coils used with the motors for which they are intended and on a car of the proper size, will, in the city streets, just about double their cold resistance and will very nearly hold this value throughout the day. But where a starting coil is abused, either by the use of the resistance notches too much by the motorman, or by the use of the coil on a car three times the size that it is designed for by the management, its resistance will be trebled and it may even get so hot as to set the bottom of the car on fire. When a coil gets so very hot the car is apt to notch badly; it will jump when one notch is reached, and will not appear to respond at all on some other notch. The resistance coils, as they come from the factory, are so designed that, on a car of given weight equipped with motors of a certain output, the car will at first start with a slight jerk when the controller is put on the first notch, but after the car has made part of a trip and the coil has heated up and its resistance somewhat increased, the start will be much smoother.

**25. Effects of Overloading Motors and Resistances.** As a rule, the motors and their controlling devices are very much abused on most roads, in the following manner: A lot of motor equipments of a certain horse-power are bought, say, to be put under a number of 16-foot horse cars that have been slightly changed to meet the requirements of electric service. These cars are small and light, the road is perhaps level, and the runs easy with a lay-over at both ends. In the course of time the traffic grows, the road is extended into the country, where it must go up long grades, and, in order to hold more people, new cars are bought, that are longer and larger, and, almost before it is realized, the same little motors that glided along so smoothly on a level road and under a 16-foot body are called on to tug a 32-foot 8-wheeler over 5 and 6 per-cent. grades; then, because the motors revolt at this abuse, they are condemned, cast aside, and new ones bought from some other company. In many cases on record, the starting coils are the first devices to show the effect of abuse. As soon as the starting coils begin to come in short-circuited, roasted, and melted, they are replaced by coils that will "stand more current"—coils perhaps better adapted to start a pair of motors twice the size—with the result that the car starts with a current that ought to blow the main motor fuse, if the motors are fused for the proper protection. The final effect of such a change is to roast the fields of the motors and to blow up the controllers. When starting coils commence to give a great deal of trouble, the idea that a coil of larger current-carrying capacity is needed is the correct idea, but it must be carried out with the condition in mind, that the resistance of the coil must be kept the same; for example, to double the current-carrying capacity of a given coil, and at the same time keep its resistance the same, the weight must be four times as great, because, not only is the size of the wire doubled in order that its capacity may be doubled, but its length is also doubled in order to bring the resistance back to its former value.

**26. Arrangement of Coils for Increased Current Capacity.**—In Fig. 24 (*a*), *r* is a resistance coil of given resistance, say 2 ohms, and it is desired to arrange several of these coils so that their current-carrying capacity shall be doubled but their combined resistance remain the same as that of the single coil *r*. The resistance between points *x* and *y*, Fig. 24 (*a*), is 2 ohms; the resistance between points *x* and *y*, Fig. 24 (*b*), is 1 ohm, because here there are two wires in multiple and the current has twice as large a path to go through, and the resistance of the two in multiple is half as great as that of one wire alone. Also, the two paths will carry twice as much current as one path will, in the same way that two pipes of the same size tapped into a cistern at the same level will let out twice as much water as one pipe. Fig. 24 (*b*), then, represents the condition where the current-carrying capacity has been doubled, but the resistance has been halved; in order to bring the resistance back to its former value, it is only necessary to connect in series two of the pairs shown in Fig. 24 (*b*), when the combination shown in Fig. 24 (*c*) is obtained. This combination contains four such coils as that in Fig. 24 (*a*), and is therefore four times as heavy.

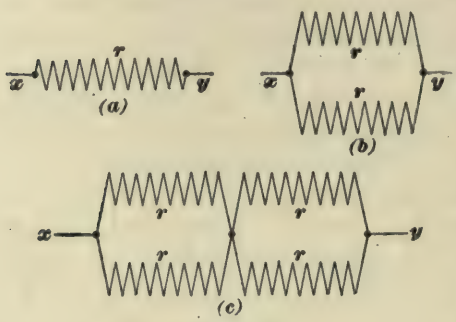


FIG. 24.

---

GENERAL-ELECTRIC RESISTANCE COIL.

**27.** In Fig. 25 is shown the type of starting coil made by the General-Electric Company. It consists of ordinary band iron folded back and forth with a ribbon of asbestos in between each fold. This iron and asbestos is built up into divisions called panels, and these divisions, set into porcelain separators, are secured to the iron case that is fastened to the

under part of the car floor. The panels can be connected in several combinations of series and parallel by means of binding posts. When these starting coils are sent out with an equipment, the binding posts are marked to correspond with the marks found on some of the wires in the car-wiring hose, also shipped with the equipment.

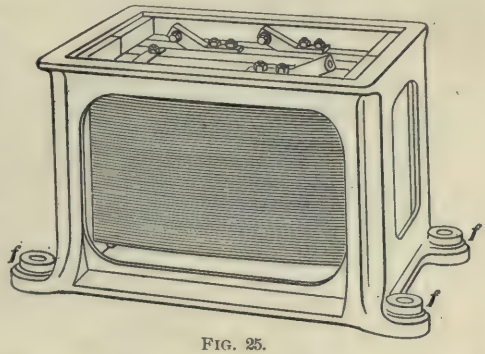



FIG. 25.

In the feet *f*, *f*, *f* used for bolting the coil to the floor, are insulating bushings to prevent the bolts that pass through the car floor from coming in contact with the iron frame.

---

### WESTINGHOUSE RESISTANCE COIL.

**28.** In Fig. 26 is shown the type of resistance coil made by the Walker and Westinghouse companies. The cut is made from a Westinghouse coil. This coil is made of band iron insulated entirely with mica, and up to certain limits of abuse it is not affected by either heat or water. A single coil, such as that shown in the figure, is called a barrel, and the proper starting coil for any size motor can be made up of two or more of these barrels. Fig. 27 shows the method usually adopted for hanging a two-barrel starting coil.

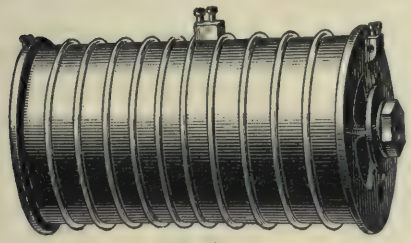


FIG. 26.

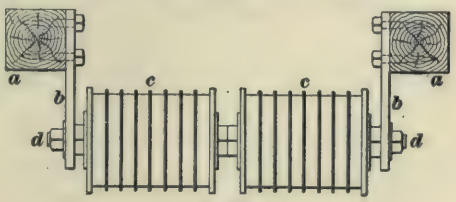



FIG. 27.

Where more barrels are required, more sets can be hung in the same manner alongside of one another. In Fig. 27, *a*, *a* are two of the car sills; *b*, *b* are two strap-iron hangers through

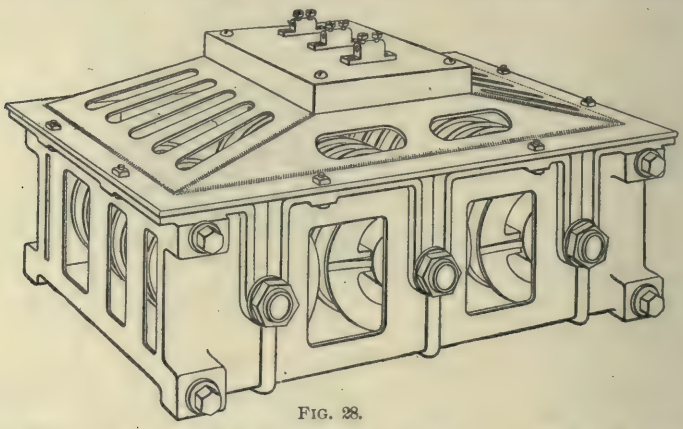


FIG. 28.

which passes a rod *d d* supporting coils *c*, *c*. Fig. 28 shows a Westinghouse resistance mounted in an iron frame.

---

JOHNSON RESISTANCE COIL.

**29.** Fig. 29 shows the starting coil made by the Johnson Company. This coil is made on the same principle as that of the Walker and Westinghouse companies—of band iron—but, like the General-Electric Company's coil, it is insulated with asbestos ribbon. The four feet are provided with insulating bushings to insulate the bolts from the iron frame, which is always alive. The coil is bolted to the under side of the car.

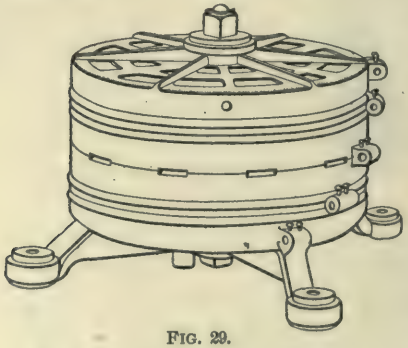


FIG. 29.

**30.** All coils that bolt directly to the car floor should have over them a sheet of $\frac{1}{4}$-inch asbestos to protect the car floor from the excessive heat.

## SHUNTS.

**31. Use of Shunts.**—The General-Electric and Johnson companies are the only companies that have adopted the use of shunts to any extent, and even these are doing away with the practice. The shunt, as has been explained in a previous Paper, is a device by means of which the speed of a car is increased. The shunt notch should always be used as much as possible, because it relieves the fields of current and lessens their heating. On the other hand, the shunt notch should not be used in climbing grades, because the full-field notch has more pulling power per ampere of current passing through the motors; and a car will climb a hill on less current when the controller rests on the full-field notch (the notch next to the shunt or loop notch where all resistance is cut out of the starting coil) than it will on the shunt notch. The full-field affords more pulling power than the shunted field, because the pulling power of a motor depends very much on the amount of current flowing through the field and the armature coils. On the full-field notch, the total current flows through both the field and the armature, but on the shunt notch part of the current passes through the shunt, thereby weakening the field. True, the weakening of the field lets a much larger current through the armature, and the car will climb the hill in much less time, but the tax on

FIG. 30.

the motor is much greater and so is the demand on the power house. To illustrate more clearly the effect that shunting the motor's field has on the pulling power for a given current, consider the action of a car under the following conditions, when the controller is put on the first notch, where the resistance of the starting coil practically limits the amount of current that shall pass through the car: Take a car, cut one

motor out, by means of the cut-out switch, and short-circuit the fields of the remaining motor, as shown in Fig. 30, by holding a piece of copper wire across the field leads, and it will be found impossible to move the car on the first notch as long as the wire is held across the field leads. If, without throwing the current off, the piece of wire be removed, the car will start in the same way that it always does when using but one motor. Again, if an extra starting coil is laid on the platform of the car and connected into the overhead switch, as shown in Fig. 31, the overhead switch then being

FIG. 31.

put off and the controller handle advanced to the full-field notch while the brake is set up hard, a current will flow through the car upon closing the overhead switch, but it will not give the motors pulling power enough to start it; if the brake be now eased off until the car begins to move and the brake dog be put into the ratchet wheel at this point, the current being thrown off at the same time by means of the overhead switch, the following is the result: The current that the starting coil allows to go through is just sufficient to start the car when the motor has a full field; if the controller handle be now advanced a notch, cutting in the shunt, and the overhead switch be put in, it will be found necessary to ease off the brake still more before the car will start on a shunted motor, thus proving that shunting the field decreases the starting power. The use of the extra starting coil is very necessary, because when the controller handle is on the full-field and shunt notches, the regular starting coil under the car is entirely cut out and the extra coil alone limits the current to a safe value. It is not wise to try the test without the extra coil, for two reasons; one of them is that with all resistance cut out of circuit, the brakes cannot hold the wheels still; the other reason is, that with such a large current flowing, some working device may be strained or burned.

### THE JOHNSON SHUNT.

**32.** Fig. 32 shows the very unique form of shunt made by the Johnson Company. It is so simple that it explains

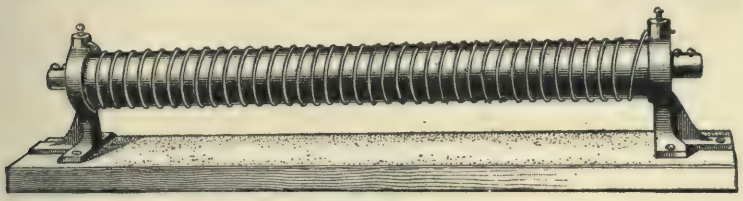


FIG. 32.

itself. It consists of a special wire coiled on an asbestos roller, held by two terminal castings screwed to a board. Its ventilation is the best to be had.

---

### THE GENERAL-ELECTRIC SHUNT.

**33.** The General-Electric Company's shunt is practically the same as the starting coil, only there are fewer panels of resistance used.

**34.** The Walker and Westinghouse companies use no shunts, nor do the General-Electric and Johnson companies on their latest type of motors.

# CAR EQUIPMENT.

(PART 3.)

## CONTROLLERS AND WIRING.

### OLD RHEOSTAT CONTROL.

**1. Introductory.**—By *rheostat control* is meant control by means of a resistance without the aid of any other device; that is, a resistance coil or starting coil of ample size to do the work is used, not only to start the car, but also to regulate its speed after it is started. The band iron or wire with which the rheostat is made up must be of sufficient current-carrying capacity not only to start the car under very trying conditions, but to stand, without excessive heating, the current that the car uses on the lower and intermediate speeds, so much used in the ordinary traffic of a crowded city street.

**2.** Other systems of control have been devised and used, and they will probably be considered in the order in which they approach the present perfected system of series-parallel control. This order may be considered as follows: *The rheostat method, the commutated field method, the series-parallel method*, and the more refined method of *multiple units*, now used in train work.

#### RHEOSTAT METHOD.

**3.** The rheostat method has been selected as the one through which to convey general ideas to the student's mind, because not only is this method the simplest, but up



For notice of the copyright, see page immediately following the title page.

to recent years it has been more used than any other. It is still used, and almost any old motorman will recognize it, from description, as the old T.-H. system with the gas-pipe controller, taking up very little room on the front of a car.

**4. Description.**—Figs. 1, 2, and 3 will give a fair idea of the old T.-H. rheostat. Fig. 1 shows the device upside down from that generally seen on a car. *F*, *F*, *F* are feet cast on the frame; these feet are drilled and provided with insulating bushings, through which pass the three bolts that secure the frame to the under part of the platform. *T* is a drum on which works a chain attached to a sprocket wheel

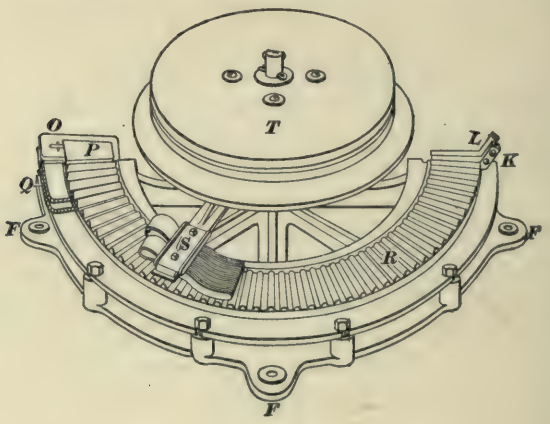



FIG. 1.

connected to the rod on the upper end of which rests the controller handle. The sprocket wheel is smaller than the drum, so that in order to move the trolley contact shoe *S* from the off-position *O* to the shunt or loop position *L*, it is necessary to give the controller handle from two to three complete turns. This insures a much smoother handling of the car and makes the controller very much easier to work. *R* is the resistance itself, which is made up of stampings of sheet iron insulated from one another by sheets of mica. The iron stampings are not entirely insulated from one another, but are sufficiently longer than the mica sheets to

allow their ends to touch, thus forming a continuous band of metal with several hundred joints in it; the radial rib-like-looking segments sticking up so plainly are iron castings built up with the stampings and mica plates and are provided in order that the shoe $S$ may make good contact. At ($a$), ($b$), and ($c$), Fig. 2, are shown, respectively, the iron stamping, the mica plate, and the cast-iron contact rib. $K$ is a copper rib that marks the position in which the shoe cuts all resistance out of the rheostat; $L$ is a second copper rib that cuts the shunt or loop into circuit as soon as it makes contact with the shoe. These two ribs $L$ and $K$ are made of copper to improve the shoe's contact in the final or running position, the two forming a kind of copper cradle for the iron shoe to rest in. $P$ is an iron contact plate, at the off-position, to improve the magnetic circuit excited by the blow-out coil $Q$, and provided to extinguish the arc that occurs when the current is shut off, and which would be a very bad one, were some means not provided for putting it out quickly.

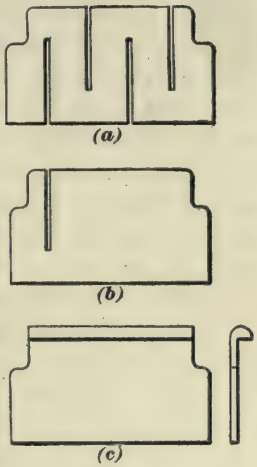


FIG. 2.

**5. The Blow-Out Coil.**—Fig. 3 is a diagrammatic sketch of the T.-H. rheostat shown in Fig. 1. $T$ is the trolley wire leading from the fuse box and lightning arrester; $S$ is the iron contact shoe on the end of the rheostat arm $A$; $P$ is the iron contact plate at the off-position, and $R$, $K$, and $L$ have the same meaning as before; $Q$ is the magnetic blow-out coil; $Q$ is provided with an iron core, one of whose pole pieces is the iron contact plate $P$. The ordinary course of the current entering the rheostat at $T$ is $T$–$A$–$S$–$P$–$Q$–$R$–$K$; as long as shoe $S$ rests on any part of

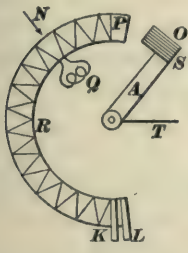


FIG. 3.

the resistance $R$, between $P$ and $N$, the current must pass through blow-out coil $Q$; therefore, whenever the shoe is thrown to the off-position, the arc, which tries to follow the shoe, is quickly ruptured by the magnetic field due to $Q$. The resistance part of the rheostat is divided into two sections joined together only through coil $Q$. When the shoe $S$ is put on $P$ and moved around counter-clockwise, the coil is in circuit until $S$ reaches position $N$, when it is cut out. The effect of coil $Q$ on the arc is very marked to the eye, if the arc on the shoe be compared with that which takes place between the trolley wheel and the wire when the pole flies off. The arc on the shoe is short and globular in shape, and is extinguished with a kind of explosive effect, while the arc between the wheel and wire is long-strung-out and hairy, and gives rise to more vapor, showing that more burning is done, and, consequently, more injury to the affected parts.

**6. Remarks.**—The rheostat, if of ample capacity to handle, without undue heating, the current of the motor or motors that it is called on to control, is a durable device and has some great advantages over the more improved methods of control. It is true that under the proper conditions the series-parallel controller is more economical (from the point of view of current consumption) on the intermediate speeds and at starting, but how often are the required conditions fulfilled? A series-parallel controller must be handled properly, or it will draw a larger maximum current from the power house than will the rheostat, and in crowded cities the time tables are usually such that the most conscientious motorman cannot fail to abuse his car. A fair comparison of the merits and demerits of the two systems of control will be made later.

**7. Location of the Rheostat.**—Where there is a single rheostat and it is desired to control the car from both ends—a double-ender—it is customary to place the rheostat under one end as usual and to connect it to the controlling handle on that end in the ordinary way. The handle on the removed

end operates the rheostat by means of a wire rope passed along a system of pulleys to the drum *T*, Fig. 1, on the rheostat. It has also proven practicable to hang the rheostat under the middle of the car and to connect both controlling handle rods to the drum by means of the wire rope. On some roads the rheostat handle is turned in the direction of the hands of a clock to put the power on, while on other roads the handle must be turned counter-clockwise. The reason for this difference is that most mechanics hang the rheostat upside down, as it is intended to hang, for the reason that any water, mud, or other foreign matter that gets on the plates, has a chance to fall off. When hung in this manner, the handle must be turned clockwise, to put the controller on, that is, to start the car. Others claim that it is better to set the controller as shown in Fig. 1, because the shoe is then less liable to give trouble from poor contact. In any case, the rheostats should all be hung alike, so that the motorman may get used to one way of throwing them off; otherwise he may get confused occasionally, throw the handle the wrong way, and instead of throwing the current off, put the motors around on the loop or shunt.

---

### ONE MOTOR AND ONE CONTROLLER.

**8. Connections.**—Figs. 4, 5, and 6 ought to give a very clear idea as to how a single motor is connected, when controlled by a single rheostat on a single-ended car.

**9. Full-Field Control.**—Fig. 4 shows the connections in their simplest form, when the motor field has neither a shunt nor a loop. *T* is the trolley; *F.B.*, the fuse box; *L.A.*, the lightning arrester; *T'*, the trolley connection on the rheostat; *S*, the contact shoe that makes contact first with plate *P*, and can be moved around on resistance *R* between the limits of plate *P* and terminals *K* and *L*; *F* is the motor field; *X*, the reverse switch, to the two top binding posts of which is connected the armature *A*; *G* is the ground wire, to which is connected the ground splices from the reverse

switch and from the lightning arrester. When $S$ makes contact with $P$, the ordinary path of the current is $T$–$F.$ $B.$–$L.$ $A.$–$T'$–$S$–$P$–$R$–$K$–$F+$ –$F-$ –2–3–$A+$ –$A-$ –4–1, through the ground wire, to the ground at $G$. If the rheostat arm is turned round until the shoe $S$ reaches the dotted position $S'$, and that part of the resistance that has been passed over, marked $r$, cut out, a larger current passes through the

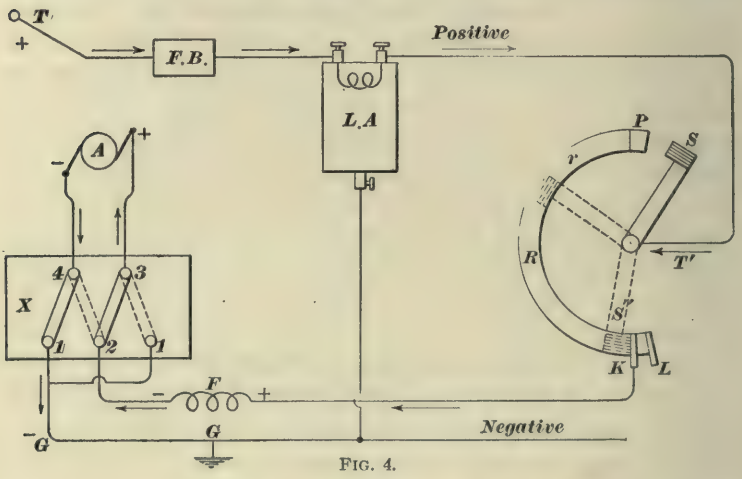



FIG. 4.

motor, making it run faster and giving the car greater speed; if the contact shoe is still farther advanced until it reaches the dotted position $S''$ and touches the contact plate $K$, all the resistance in $R$ is cut out, the path of the current is $T$–$F.$ $B.$–$L.$ $A.$–$T'$–$S''$–$K$–$F+$ –$F-$ –2–3–$A+$ –$A-$ –4–1 to $G$, and the motor runs at its greatest speed.

**10. Marking of Terminals.**—It will be noticed that the terminals of the armature and field are marked $A+$, $A-$ and $F+$, $F-$, respectively; the end of a field at which the current enters is always marked + (plus) and the end at which the current leaves is marked − (minus). This marking is done for several reasons: in the first place, if the end of every wire is marked and the binding post on the device to which that end goes is marked also, it makes the connecting up of the car an easier and quicker job; also, if the car body

must be raised from the truck, or if for any other reason the motors must be disconnected from the car wires, it is much easier to get the wires back into their proper places; again, it is an established rule on all roads that the reverse handle shall indicate by its position in which direction the car will move when the rheostat is put on. If the reverse handle points ahead, the car should move ahead; if it points back, the car should move backwards, and on up-to-date controllers, when the reverse handle is in a neutral position, it should be impossible to move the car at all. By properly marking the terminals it is a simple matter, after a car is once properly connected, to connect any number of others just like it. With marked terminals it is much easier to talk about the connections and to think about them also. By making a drawing of the wiring, and lettering it as above, it is possible to predict how a car will act under certain conditions, and also to diagnose a case of trouble from symptoms just as a doctor does a case of sickness. The time and labor saved by marking the terminals is not so great on rheostat control, because, in the first place, there are not so many wires, and the points to be connected are more readily distinguished by their difference in appearance than is possible on an up-to-date series-parallel controller having twelve or fifteen connecting posts, all of which look just alike.

**11. Use of Reverse Switch.**—The current paths given in Art. **9** assume the reverse to be in the full-line position. The effect of throwing the reverse switch to the dotted position, is to reverse the direction of the current in the armature and thereby to reverse the direction of motion of the car. The theory of this action was taken up in *Motor Principles*, Part 2, and will not be repeated

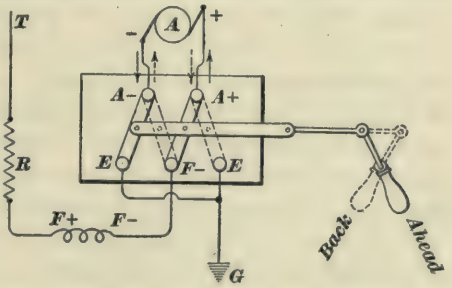


FIG. 5.

here, but the action of the switch can be made more clear by means of Fig. 5. This figure also shows how the position of the reverse handle is related to the position of the switch blades. In this figure, the car is supposed to be going ahead, as indicated by the position of the reverse handle, and the path of the current is $T$–$R$–$F+$ –$F-$ –$A+$ –$A-$ –$E$ to the earth; the current enters the armature on the right hand side, as shown by the full-line arrowhead. If the reverse handle is thrown to the back position, and the switch blades drawn to the dotted position, the current path then becomes $T$–$R$–$F+$ –$F-$ –$A-$ –$A+$ –$E$ to the ground. The current now enters the armature at the left-hand side, as shown by the dotted arrowheads, reverses the polarity of the armature, and with it the direction of motion of the car. The direction of the current is reversed in the armature, but is not reversed anywhere else.

**12. Remarks.**—The two outside bottom binding posts are both marked $E$ because they are connected together; this connection is generally made inside the switch itself. If a car runs in the same direction, whatever may be the position of the reverse handle, it indicates that some mechanical connection or coupling is broken loose, and, therefore, that whatever may be the position of the reverse handle, the switch blades, being disconnected, remain in the same position all the time.

**13. The Loop.**—Fig. 6 shows the connections for the *loop* method of control. The loop wire runs from some part of the field winding to the contact plate $L$ on the rheostat; this contact plate is not in metallic connection with contact plate $K$ until the rheostat arm is moved so far around, that shoe $S$ reaches its final position, shown by the dotted lines. The path of the current is the same as that given in connection with Fig. 4; that is, the amount of rheostat resistance in circuit depends on the position of the shoe. When the shoe rests on $P$, all of $R$ is in circuit; when it rests on $K$, none of $R$ is in circuit; and when it rests on any point

between $P$ and $K$, the amount of resistance in circuit depends on how far $S$ is from $K$. As soon as $S$ rests in the cradle formed by $K$ and $L$, it makes contact with both, and the current from the shoe has two paths by which it can reach point $o$, where the loop tap is brought out of the field coil. One path is $K$–$r$–$o$, which includes that part of the field coil marked $r$; the other path is the loop wire $L$–$o$, which has no resistance to speak of. The resistance of path $L$–$o$ is so

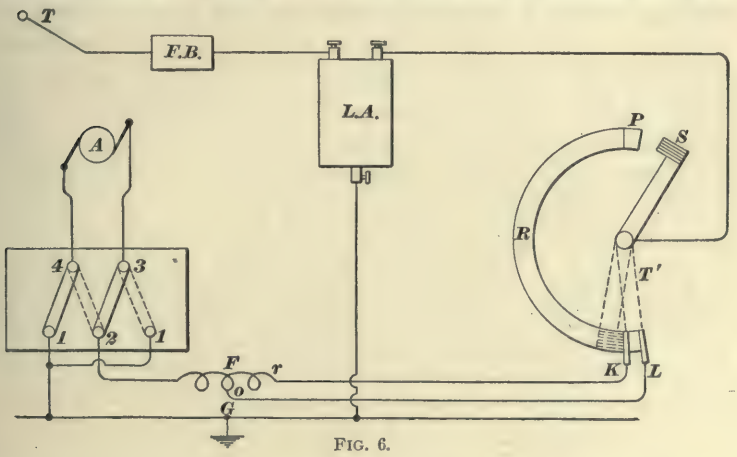



FIG. 6.

low as compared to that of path $K$–$r$–$o$, that the latter practically short-circuits the $r$ portion of the field and robs it of all the current; in other words, the loop wire cuts out some of the turns of the field coil and makes them just as inactive as if they were not there. As explained in *Motor Principles*, Part 2, the effect of cutting out some of the field turns is to decrease the number of lines of force cut by the revolving armature wires, and thereby to lessen the counter E. M. F. This allows a larger current to flow through the motor and causes the armature and the car to run faster. The loop wire, then, simply weakens the field by short-circuiting some of the turns of wire in the field coils. The loop is found only on motors having one or two field coils. There is no general reason why this should be the case, but it is due to the fact that the manufacturing companies probably found

out, at about the same time, that the four-field type of motor was the best motor, and, that for various reasons, to be talked of later, the loop and shunt were very good devices to do away with. The loop lead on a motor field is generally the middle lead of the three, and, where there is no loop, the field coil has only two leads. A very common expression among motormen is, "put her on the loop." This means that the rheostat arm or controller handle is pushed round as far as it will go, which, if the motors have a shunt or loop, brings it into action, as shown in Figs. 6 and 7. Another common expression is, "give her seven." This originated from the fact that the earlier forms of controller had seven notches, so that seven was the fastest notch on the controller. "Give her seven" means, then, in a general way, to push the controller handle as far round as it will go, to get the highest speed.

**14. The Shunt.**—Fig. 7 shows the connections of the shunt method of control as carried out by means of a rheostat. The connections are practically the same as those of

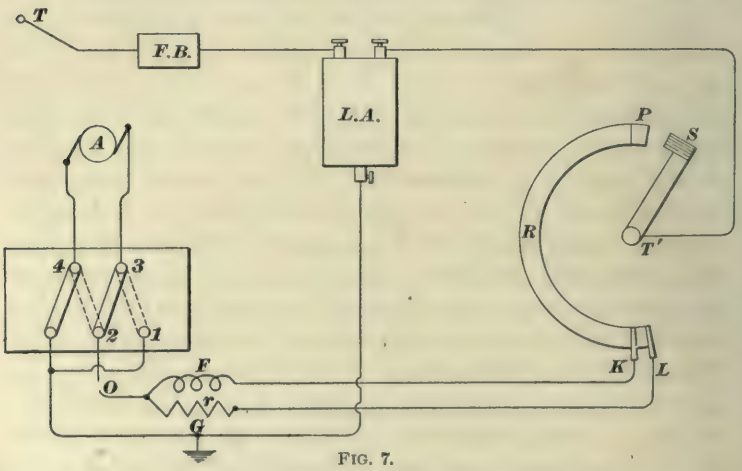



FIG. 7.

Figs. 4 and 6, with this difference, that in Fig. 4 there is no shunt or loop, while in Fig. 6 the loop wire is in multiple with only a part of the field. In Fig. 6 the loop wire

contains a low resistance $r$, and when the shoe makes contact with both $K$ and $L$, the resistance $r$ is in multiple with the whole field. The shunt, then, is nothing more or less than a loop wire having more resistance in it than regular loop wires have, and in multiple with the whole field instead of a part of it, as loop wires are. In fact, any rheostat or controller that will handle a loop will handle a shunt, because in both cases there is one end permanently attached to the field, and one free end connected to the rheostat or controller.

In Fig. 7, the course of the current is the same as in Fig. 6. When the shoe rests on $K$ and $L$, the current, in order to get to point $O$, passes through two paths that are in multiple; path $K$–$F$–$O$ includes the field and path $L$–$r$–$O$ includes the shunt. As the shunt generally measures about three times as much as a warm field, the shunt steals away from the field one-third of the total current—not one-third of the total current that the field would get were there no shunt in use, but one-third of the total current that passes through the motor when the shunt is in use. It must be borne in mind that the final result of bringing the shunt or loop into action is to increase the speed of the car, and the car cannot be made to go faster under given conditions without its being furnished with more power; this increase in power is provided by the increase in the current due to the weakening of the motor field by the shunt. The idea that is intended to be brought out here is an important one, thus: assuming that any given machine—dynamo, motor, steam engine, gas engine, waterwheel, or what not—is running under the best possible conditions, it is impossible to get more work out of the machine without putting more work into it. Of course, if the machine is not running under good conditions, it is often possible to increase its output without increasing its input by making some change in the machine itself that will improve its working; that is, it is very often possible to make a change in a machine that will improve its efficiency. The same amount of work put into a machine that has been changed is more economically converted—less of it is

wasted and more of it is used. For any given machine running under given conditions, however, to get more work out of it, more work must be put into it. This little talk is put here out of place simply to emphasize its importance.

---

### GENERAL REMARKS ON THE USE OF SHUNTS.

**15. Advantages of Shunts.**—As has been stated before, the shunt and loop have been left out in the design of up-to-date equipments. They have their advantages and they have their disadvantages—principally the latter. The main advantage in their use is, that any desired maximum speed, within the motor's output, can be obtained without sacrificing any of the motor's starting power. The reason for this fact has been talked of elsewhere, but for fear that it may not be identified with the case in question, it will stand repeating. It has been learned that a motor will not start at all if its field coils are short-circuited; also, that if its field coils are partially short-circuited, it will take more current to start than it will take on full field. The shunt and loop are really partial short-circuits of the motor's field, and were they so connected as to be in action on the starting notches, the motor's starting power would be greatly decreased. With a car of given weight it will take a much larger current to start it under given conditions of load when the motor field is shunted on the first notch than it will if the field is clear. On an equipment designed to run without any shunt at all, the motors must be so designed (the field so weakened) that the maximum speed required can be obtained without the use of a shunt. This is equivalent to saying that since the field must be so weakened as to give the required speed on the last notch, the field must be weaker on all the other notches than it would be were it designed to run with a shunt or loop on certain notches. It follows, then, that an equipment designed to run without a shunt or loop has its field so much weakened that it virtually runs with a loop or shunt in all the time. Another advantage is, that when the shunt or loop is used, one more

economical running notch—and, in the case of series-parallel controllers, two more—is added to the controller index. Still a third advantage, which refers only to series-parallel controllers, is that on the last series-notch, an increase of speed is a very desirable feature, because the motors are then in a position to quickly work up a counter E. M. F., and are therefore better prepared to look after the violent change to which they are subjected in going from series to parallel. Every motorman knows how badly the car will jump if the controller handle is put right around to the loop before the car has been allowed to run its length; whereas, if the car is under good headway, the controller handle can be advanced rapidly without the car's apparently responding to the notches at all. Another effect of thus weakening the motor field is to increase the amount of current necessary to start the car. In order to get a larger starting current, the resistance of the starting coil must be made lower, with the result that the controllers give more trouble from burning and grounding. Excessive flashing due to any cause whatever chars the controller insulation and a short-circuit follows. Another indirect effect of dispensing with the loop or shunt, is to increase the liability of blowing a fuse when the car is reversed under headway. This is so, for the following reason: In order to get more starting current, the resistance is made lower, and when the car is reversed while in motion, the counter E. M. F., for reasons to be stated later, adds itself to the line voltage and the two together can send current enough through the motors and starting coil to blow the fuse. This is a fact on cars equipped with any kind of motors, whether they have a shunt or loop or not, but is more marked on motors of recent type used in conjunction with a very low resistance starting coil. Theory, then, seems to throw its weight in favor of using shunts and loops, on the ground that the car has more starting power, and also because any desired speed within safe limits may be secured without decreasing the starting power, since the loop or shunt is in action only after the car is under headway.

**16. Objections to Shunts.**—It is all very well in the design of a street-car equipment to have due regard for points that theory stamps as good, but, as is usually the case, practice must have a chance to condemn or at least modify the enthusiasm of the inventor or the originator. Now theory favors the use of shunts and loops, and gives good sound reasons for doing so, but years of trial have shown that, although some sacrifices have to be made, a car is better off, on the whole, if equipped with motors that require no shunt or loop, because shunts and loops are very much in the habit of getting out of order and causing a great deal of trouble. Street-railway companies want motors that go into service and stay there, and that do not require to be run into the house very often for repair. A motor's record is not dependent on its own good behavior alone, but on the behavior of every electrical device on or under a car. If a rheostat, resistance, shunt, or loop gets out of order, the effect is soon seen on the motor.

**17. Faults in Shunts.**—In considering the failings of shunts and loops, several conditions may be supposed to exist, and their symptoms and effects studied. Suppose a shunt, Fig. 7, to be entirely short-circuited. This would amount to the same thing as making path $L$–$r$–$O$ a piece of ordinary copper wire; in other words, the shunt $r$, having two or three times as much resistance as the field coil $F$, would be replaced by a piece of wire having practically no resistance at all, with the result that the field would be short-circuited on $S$ making contact between $K$ and $L$. The effect of a shunt becoming dead short-circuited is, that the motor bucks and blows up as soon as an attempt is made to put the shunt in action. The reason for this is, that the field coil, being robbed of all current by the short-circuit, can furnish no lines of force for the armature wires to cut; the armature is thus deprived of all counter E. M. F. and allows an enormous current to enter. This current burns the brushes, and gives off a conducting vapor across which the current jumps to the ground by way of the motor frame.

As soon as this happens, the main motor fuse blows. If a shunt becomes partially short-circuited, due to the roasting of its insulation, or to the presence of some foreign metal, the fact is indicated by the car running faster than it ought to on the shunted position; the brushes also spark badly and the commutator gets rough. If the defect is not reported in time, the car begins to buck on the shunted position and finally blows up.

**18. Slow-Running Cars.**—Motormen very soon become closely acquainted with the cars assigned to their runs, and they learn to pick out the fast cars and the slow ones. They do not like a slow car and will turn it into the house on the least real or fancied pretext. It is a remarkable fact that especially slow cars always give three times as much trouble with their brakes as especially fast ones do, and it should be just the other way, because the brake has much harder usage on a high-speed car. The reason the slow car gives more brake troubles is this: In giving testimony at a trial in a damage suit, a motorman naturally wants to clear himself: if he should go on the stand and swear that the accident was due to poor brakes, and that the condition of the brakes was reported to an inspector before the accident happened, his testimony would be very damaging to the company's cause. The inspectors have orders to turn a car in when its brakes are reported as being in bad order; more often than not there is nothing the matter with the brakes, and after an inspection, the car is given to the next crew out. The men know this, and to a certain extent are justified in resorting to the ruse of getting rid of a slow car, for when a car is very slow, the chances are there is something the matter with it and it should not be on the road.

**19. Causes of Slow Running.**—If a car is reported to be slow, either of two things is likely to be the matter with it—the shunt circuit may have an open circuit in it, or the contact shoe *S*, Fig. 7, may be out of order so that it makes poor contact with, or does not get round far enough to touch

*K*, thereby leaving a part of *R* in circuit all the time. In the first case, the shunt circuit may be opened in any of three ways: the shunt itself may be burned out; it, or some wire leading to it, may have a loose connection; and, finally, shoe *S* may fail to make contact with plate *L*. In any of these cases the shunt is cut out and the car speed fails to respond when the shunt position is reached. Aside from the speed reduction that follows, the open circuiting of a shunt is a very bad thing for the fields; if they are intended to run with a shunt, they are very apt to roast if run for any length of time without a shunt. When the shunt is in action, it takes part of the current and the fields do not heat so much; when the shunt is out of action the fields get all the current; for this reason it is well to use the shunt as much as possible. If a motorman is ahead of time, let him rather put the rheostat on the loop, throw the power off and coast awhile, than run along on the resistance. If this be done the motor will not become nearly so hot. One other fault liable to arise in connection with using a shunt and a rheostat, results in having the shunt in action all the time; plates *K* and *L* should be insulated from each other. Of course, when the rheostat is connected up as in Fig. 7, *K* and *L* are connected by path *L*–*r*–*O*–*F*–*K* around through the shunt and the field, and will ring up together when tested with a magneto-bell; but before any connections are made to *K* and *L* they should ring clear. Occasionally, through some defect in the insulation between them, they get together, and there are cases on record where some wireman not understanding their relations has actually connected them together. This, of course, amounts to the same thing as splicing the shunt wire on to the field wire permanently, thereby rendering plate *L* useless and putting the shunt in action all the time. Such a fault or mistake robs the car of starting power, decreases the life of the shunt, and increases the work on the armature because the car starts with a weak field and runs with it throughout the range of the rheostat. When the shunt is cut in permanently, there is not the usual increase in the speed when the shoe makes contact with

plate *L*. The permanent shunt has been resorted to on several occasions where the fields were roasting very rapidly, and it was desired to save them until their design could be changed to meet the conditions; but in any but extreme cases the practice is a bad one.

**20. Summary.**—The foregoing faults and their symptoms may be summed up as follows: A short-circuited shunt causes the motor to buck and blow up when the shoe reaches the shunt position. To relieve the trouble for the time being, cut or disconnect the wire running into plate *L* and turn the wire up so that it cannot touch the ground. A roasted or partially short-circuited shunt will increase the speed abnormally on the shunt position, will heat itself, will cause the armature to heat, will make the brushes spark, and, if in action going down hill, will probably cause bucking. For temporary relief, disconnect the shunt as above and make a report of it to the barn boss, or to whomever such matters are reported. A cross between plates *K* and *L*, or between the wires running to them, will make the car slow at starting, but faster running than usual as the shoe moves around on *R*; the maximum speed will be the same and there will be no natural response in the speed when the shoe touches *L*. The armature and shunt will both run warmer than usual. If the cause cannot be located by inspection, report it. An open-circuited shunt makes the car slower on the shunt position, and the speed fails to increase when that position is reached; the fields also become much warmer. If a careful inspection reveals no loose connection, broken wire, or poor shoe contact with plate *L*, report the matter to the inspector.

---

### GENERAL REMARKS ON LOOPS.

**21. Distinction Between Loop and Shunt.**—While the office and the action of the loop are similar to that of the shunt, the fact that the loop wire shunts only a part of the field coil makes the symptoms and effects of disorder in this

device differ from those that characterize the several disorders liable to take place in a shunt. The main distinction between the office of a shunt wire and that of a loop wire is, that at a certain position on the rheostat, the shunt wire cuts an additional device, the shunt, into action, and whatever may happen to this device, its effect can be felt only when the stated position is reached; in other words, the shunt is in action on only one position, and defects in it can show themselves only on this position; whereas the loop wire, at a given position on the rheostat, cuts out of action a device—the part *r* of the field coil, Fig. 6—that is always in action except when the loop position is reached. Therefore, if the part *r* is being considered, it is easy to see that any disorders here will show themselves throughout the range of the rheostat arm. It is necessary that some sort of understanding be had in regard to what is to be called the loop, for this reason: as a result of asking questions of street-car men in a great many parts of the country, it has been found that different men have very different impressions as to what the loop really is; some call part *r* of the field coil the loop, while others claim that the loop wire *L–o* should be called the loop; as a matter of fact, neither of these parts is in itself the loop, but both parts help to form the loop when their ends *K* and *L* are brought together by shoe *S* touching both of them. It can be readily seen that when shoe *S* brings *K* and *L* together, the local circuit *K–r–o–L–S* is just as much of a loop as if it had been tied with a string. The reason, then, that wire *L–o* is called a loop wire is, that when it is brought into action, a loop is actually formed.

**22.** As a rule, street-car men have the correct general idea that when the rheostat arm is shoved around to the loop position, a certain change in connections takes place and that, irrespective of whether this change effects a cutting in or a cutting out of some device or other, its net result is the loop, which increases the speed of the car. If the speed of the car does not increase, they draw the very common-sense conclusion that something is the matter with the loop. This idea

is a correct one and will do for an office man that does not have to crawl under a car and "get 'er agoin'!" when 5 or 10 minutes' delay may mean a great deal.

---

### DISCUSSION OF THE LOOP.

**23. Short-Circuits.**—It makes a great deal of difference which part of the wiring is agreed on as the loop; if the part *L–o* is to be called the loop, then it cannot be short-circuited, because the wire *L–o*, being short and large, is nothing more than a short-circuit itself, and, in fact, is there for that purpose. An open circuit in *L–o* would decrease the loop speed of the car and cause the field coils to heat more than they should; whether due to a broken wire, an open connection, or to want of contact between shoe *S* and plate *L*. An open circuit in *L–o* renders the loop inoperative, and the car speed fails to respond when the rheostat shoe reaches the loop position. Sometimes part *r* of the field coil becomes entirely short-circuited. This may happen in any of several ways, as follows: The flexible leads may be short-circuited under the insulation of the field, or they may have been pinched together outside; plates *K* and *L*, or the wires going to them, might be in contact, but in any case, the effect of short-circuiting *r* is to get the field-weakening effect of the loop throughout the range of the rheostat. This is so, because putting the loop into action is nothing more than bringing together the two ends of *r*. The wires leading into *K* and *L* are brought from the motor where they attach to flexible field leads connected to the two ends of *r*. These two ends are, of course, supposed to come together only when shoe *S* touches both *K* and *L*, but, if through any of the faults enumerated above, *K* and *L* get together independently of shoe *S*, then the loop is already established, and the starting power of the car is very much decreased. Moreover, the rheostat and that part of the field coil not in the loop become much hotter, the intermediate positions of the rheostat arm give higher speeds than usual, and the shunt position is not felt when the shoe reaches it.

**24. Open Circuits.**—The result of an open circuit in *r*, or in the wire leading from *r* to plate *K*, is that the car will not start until the shoe touches plate *L*, and then starts with a severe jerk, because all the resistance is cut out of *R*, and the motor being directly across the line, the starting current is very large. An open circuit in wire *K–r–F*, Fig. 6, may be due to the soldered field lead melting loose, to a loose connector, to a broken wire, or to poor contact between the shoe and plate *K*. When a field lead melts loose, there is apt to be a strong odor of burning rubber; a loose connector or a broken wire may not be visible to the eye, because the connector may be well taped up, in which case the tape holds the wires in position, and wires sometimes break inside of the rubber cover without breaking the cover itself. The only way to find such a fault by inspection, is to take hold of the wire and work it up and down. In any case, no matter to what the open circuit may be due, current cannot get to the motor through the field loop *r*, but as soon as the shoe reaches plate *L*, the current travels along the loop wire *L–o*, and enters the field coil at point *o* beyond the loop part of the field, using that part of the field coil not included in the loop for starting. In case of such trouble, it is a good idea to disconnect the wire running into *K*, and put into its place the loop wire running into *L*. The effect of such a change is to do away with the enormous starting current by using the resistance in *R*. Of course such a connection must be used only to run the car to the house.

**25. Summary.**—The several failings of the loop, and the symptoms and temporary relief of such failings, may be summed up as follows: Generally slow loop speed and failure of the speed to respond properly on the loop position is due to an open-circuited loop wire *L–o*; in such a case the whole field heats more than it should. If a careful inspection fails to reveal a trouble that can be easily fixed, turn the car in and report its action to the barn boss. If the car fails to start until the shoe is moved around beyond plate *P*, and the speed fails to respond properly when the loop position is

reached, there is a short-circuit between plates *K* and *L*, or between the wires leading to them. If an inspection fails to locate the fault, disconnect the wire running into *L*, run the car to the house, and report to the barn boss, as nearly as you can, how the car acts. If the car fails to start until the shoe reaches the loop position, there is an open circuit in the loop part of the field *r*, or in some wire or connection running from the outside field lead, wire *K–r–o*. If inspection does not show the source of the trouble, disconnect entirely the wire leading into plate *K*; put in its place the wire running into plate *L*; run the car to the house, and report what you did and why you did it.

---

### PERMANENT LOOP OR SHUNT.

**26.** There is one very important point that may not have been well enough brought out in the above discussion, and it is in regard to the relative effect, in the shunt and loop methods of control, of having the devices so connected, through a fault or a mistake, that they are in action all the time. If a shunt is so connected, the fields run cooler but the shunt gets hot. If a loop is so connected, that part of the field included in the loop and corresponding in position to the shunt, runs cooler and the remaining part of the field coil gets hot. Why is this? The effect of putting the shunt or loop into action is to increase the main-motor current. The shunt is in multiple with the whole motor field; the loop wire is in multiple with only a part of the field. When the shunt goes into action it is true that the current increases, but the field gets only a part of it and the shunt takes the rest. In fact, the field gets more current just before the shunt is thrown in than it does when the car is running on the shunt, because, in the first case, the field gets all the current that there is, and, in the second case, it gets but a part. When the shunt is connected so that it is in all the time, the field at no time gets all the current, and, being thus always relieved, runs cooler; on the other

hand, since the shunt must carry a current all the time, it must, when it is intended to carry it only a part of the time, of course, heat more. With the loop, the conditions are different; since the loop wire is in multiple with only a part of the field, this part of the field is relieved when the loop wire is thrown into action; the rest of the field must carry all the increased current, due to the field-weakening action of the loop, and must, therefore, get hotter. The effect of the loop's action is really to make the looped part of the field run cooler and the part of the field outside of the loop run hotter; but as the two parts are so close together, being one continuous winding on the same spool, the heat of one part is soon conducted to the other, so that the whole field spool gets hotter. It must be borne in mind, as stated elsewhere in these papers, that when the current is increased a certain amount, the heat is increased much more than a proportional amount. Thus, when the current is doubled, the heat is four times as great; and when the current is made three times as great, the heat becomes nine times as great, and so on at the same multiplying rate.

---

### TROUBLES.

**27.** In order that a motorman may be able to tell from the action of his car, in time of trouble, just what is the matter with it, it will be necessary to suppose certain faults to exist, show how the motor acts, and why it does so. The numerous faults selected to be talked about are not faults of the imagination—it would be almost impossible to imagine in connection with an electric car any reasonable trouble, however peculiar, that has never taken place—but are faults liable to occur any time and liable to give a great deal of trouble unless the motorman has some sort of an idea as to what he is dealing with. These faults are of three classes, and will be talked about in the following order: *grounds*, *short-circuits*, and *wrong connections*.

GROUNDS.

**28.** When the insulation on a motor, or any of its controlling devices, breaks down, and the trolley current, instead of taking its natural path to earth, passes to the earth through the break-down, the system is said to be grounded, and the fault is called a *ground*. The question of grounds will be taken up in connection with Fig. 8, which, on account of having no loop or shunt, is the simplest to deal with. The complications caused by the introduction of the loop and shunt do not amount to much, but will be talked about later. In Fig. 8 the letters have the same meaning as usual. *F*+ is the

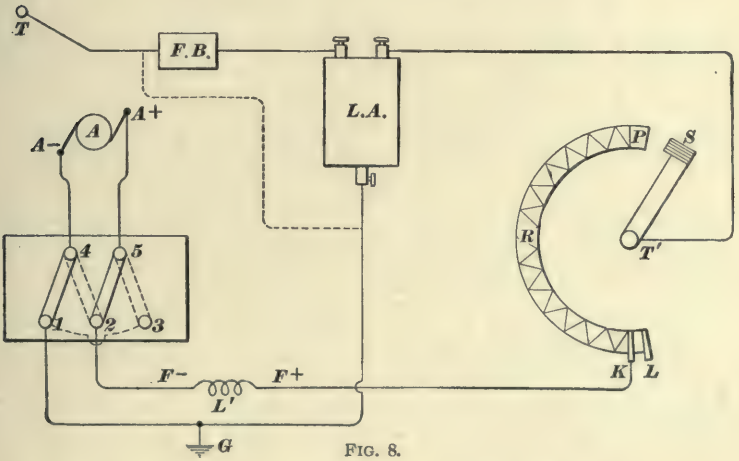



FIG. 8.

field lead by which the current enters the field, and *F*— is the lead by which the current leaves it; *A*+ is the armature lead by which the current enters the armature, and *A*— is the lead by which the current leaves it. The ordinary course of the current from the trolley to the ground is through the path *T*–*F.B.*–*L.A.*–*T'*–*S*–*P*–*R*–*K*–*F*+ –*F*— –*2*–*5*–*A*+ –*A*— –*4*–*1*–*G*, and the current will follow this path as long as no grounds exist. It must be borne in mind that one side of the circuit is always grounded, because one side of the armature is connected to the frame of the motor. This fact increases the liability of the insulation to give way, because at every

point the positive side of the circuit is separated from the negative side only by the insulation.

**29.** Fig. 9 shows the difference between a circuit having one side grounded, and a circuit having neither side grounded, as in a lighting circuit. In Fig. 9 (*a*), where one armature lead is grounded to the frame of the motor as soon as a ground occurs anywhere else, as at *G'*, the current passes through the fault to the rail at *G*.

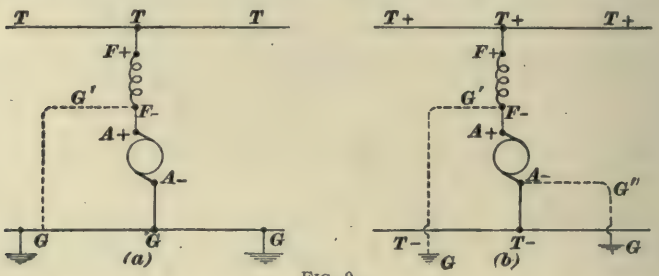



FIG. 9.

Where neither side of the circuit is grounded, Fig. 9 (*b*), the occurrence of a single ground, as at *G'*, makes no difference in the working of the motor; because, since the motor frame is not a part of the circuit, even if it does come in contact with the circuit through a single fault, no current will go to the frame because it can go no farther when it gets there. However, should another fault occur, as at *G''*, the working parts of the motor become short-circuited, because the current leaves its path through one fault and returns through the other. In other words, between points *F*— and *A*— there are two paths; one through the motor armature, the other through fault *G'* to the motor frame and back through the fault at *G''*. The two paths are in multiple, and the path through the faults short-circuits the armature path, because the counter E. M. F. of the armature makes its resistance much higher than that of the path through the motor frame.

**30.** It is easy to see, then, that a circuit having neither side grounded (a metallic circuit) has two advantages

over a circuit having one side grounded, such as a street-railway circuit with its rail return. In the first place, on a metallic circuit, such as is used on some of the trolley systems in Ohio, there is less inducement to ground, and, in the second place, the occurrence of a single ground can make no difference until another ground occurs on the opposite side of the circuit. On the other hand, the metallic circuit requires the use of two trolley poles and increases very much the cost of putting in the line work. Which of the two is the better is an open question.

**31. Grounds at Fuse Box.**—Fig. 10 is a diagrammatic sketch of the connections in Fig. 8. The letters are the same in the two figures and they have the same meaning. Fig. 10 is given because in it the path of the current, under the several faulty conditions to be named, is much easier to follow. Suppose a ground to occur on the positive side of the fuse box *F.B.* How will the car act and what will be the effect? If the fault occurs while the car is standing still, and the pole is off, or one of the hood switches open, as soon as the circuit is closed by putting in the switch or putting on

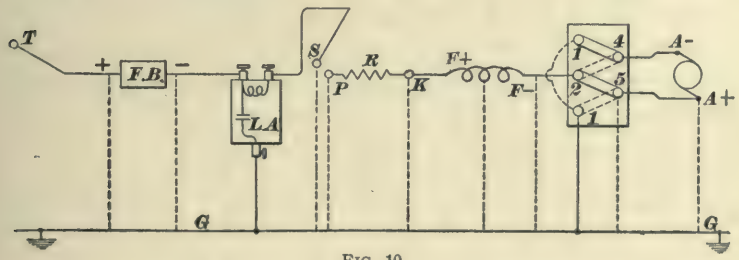



FIG. 10.

the pole, there is a display of fireworks around the fuse box, and the power goes off, but probably not until the fuse box, or even the car itself, is set on fire. As soon as the ground occurs, the current takes the path *T*–*F.B.*+ –*G*, and is so great, there being no resistance in circuit, that, unless the breaker at the power house acts very promptly, it burns out the connection that causes the ground. If the ground shows up while the car is in motion, the symptoms are exactly

similar, with the exception, that if the car is running on a level or upgrade, there will be a very perceptible halt in its speed, as a result of the motor being deprived of its power by the short-circuit. It is easy to be seen that the main trouble lies in the fact that the fuse cannot act because it is not in the circuit, and that it is impossible to put in the hood switch if the power is on, unless the fault has burned itself out. If the fault burns itself out, it is then possible to put on the pole, put in the hood switch, and operate the rheostat; but the car cannot be made to move, because, as an inspection will show, the wire running to the fuse box has been burnt off. In such cases, where the ground takes place on the positive side of the fuse box, and the fuse, therefore, cannot act, the trunk wire often burns off where it is connected to the trolley base, or where it runs into one of the hood switches, because in either of these places there is liable to be a loose connection that causes excessive heating.

**32. Grounds at Lightning Arrester.**—A ground on the negative side of the fuse box, either on the fuse box itself or on the wire running from it to the lightning arrester, also a ground on the arrester itself, or on the rheostat arm or shoe; in other words, a ground anywhere between *F.B.* and *S*, inclusive, will cause the fuse to blow as soon as the pole is put on and the hood switches put in. The lightning arrester may become grounded by the contact points fusing together. If the ground shows up while the car is in motion on a grade or level, the usual check in the speed will take place. When the fault is on the *F.B.*— connecting post itself or on the wire leading to it, the path of the current is *T*–*F.B.*+ –*F.B.*— through the fault to the ground at *G*; if on the arrester, the path is *T*–*F.B.*+ –*F.B.*— –*L.A.*–*G*; if on the arm or shoe, the path is *T*–*F.B.*+ –*F.B.*— –*S*–*G*. The symptoms for a ground between *T* and *F.B.*+ are similar to those for a ground between *F.B.*— and *S*, except that in the latter case the blowing of the car fuse further localizes the seat of the fault. The necessity of pulling down the pole or throwing off the overhead switch whenever the symptoms

point to such conditions as either of the above cannot be too forcibly impressed on the motorman. Failure to take this never foolish precaution will probably give rise to symptoms that the motorman will not be in the best position to diagnose. Always throw an overhead switch before putting in a fuse wire.

**33. Grounds at Rheostat.**—The action of a car when a rheostat is grounded depends entirely on where the ground is located on the rheostat. If plate *P* is grounded, the fuse will blow as soon as shoe *S* touches plate *P*, and the path of the current will be *T–F.B.*+*–F.B.*—*–S–P–G.* If plate *K* is grounded, the fuse will not blow till the shoe very nearly reaches *K*; and for any points in between *P* and *K*, the fuse will blow as soon as the shoe reaches the faulty point, if the rheostat itself does not blow before then. On some rheostats that have been in use a long time, the insulation between the iron resistance plates is in such bad shape that the plates have become practically welded together, and in such a condition they are almost useless as a resistance. In case of a ground anywhere on such a rheostat, the fuse will blow as soon as *S* makes contact with *P*. It should be unnecessary for an intelligent motorman to push his rheostat handle round till the fuse blows before he finds out that something is the matter. Of course, if the fault occurs while the car is under headway, the blowing of the fuse cannot be helped. But if, as is usually the case, the car refuses to start after having been running along all right up to that time, the motorman should throw the shoe on and off; if he gets no flash, the failure to start is due to an open circuit somewhere, but if there is a strong flash it shows that a current is flowing, and that there is probably a ground on the rheostat, on the reverse switch, on the motor itself, or on one of the wires leading to one of these devices.

**34. Grounds at Field:—Bucking.**—The symptoms of a ground occurring anywhere between points *P* and *A*+ are very similar. A ground on *P*, of course, causes the fuse to

blow as soon as $S$ touches $P$, but anywhere else the time of the fuse's blowing depends on how far along $R$ the ground exists. If a ground occurs anywhere between $F+$ and $F-$, or between $F-$ and $A+$, while the car is in motion, the car is apt to buck very violently, for the following reasons: A ground, say at $F-$ or $A+$, allows a strong current to flow through the fields to the earth, and the fields are thereby separately excited; that is, they are excited independently of the armature and would remain excited even were the armature circuit open. The fact of the matter is, however, that the armature circuit is far from being open. One brush holder of the armature is permanently grounded through the ground wire leading to the reverse switch, and the other brush holder becomes grounded as soon as the fault occurs. Since both brush holders are grounded, the armature is short-circuited, and the field, being separately excited, the motor acts as a short-circuited dynamo. The amount of current it can generate is, therefore, very large, causing the armature to become an abnormally strong magnet and requiring a great deal of work to pull it around against the attraction of the pole pieces. As this work can be drawn from nowhere but the momentum of the car, the speed of the car receives a sudden check as soon as the ground occurs, and this constitutes a *buck* in the truest sense. A ground on $F+$, which does not include any of the field coil, or on this wire between $F+$ and $K$, will cause the same effect as if $K$ were grounded, because the resistance between these points is so low that they are practically the same point. On this account, only a careful inspection will reveal the seat of the trouble. All the grounds so far considered have been on the positive side of the armature, with the result that in each case the armature has been cut out of the active part of the circuit, and therefore has been spared any sparking at the brushes.

# CAR EQUIPMENT.

(PART 4.)

## CONTROLLERS AND WIRING.

### OLD RHEOSTAT CONTROL.

#### GROUNDS.

**1.** The effects to be expected should a ground occur anywhere between *T* and *A*+ on the motor connections shown in Fig. 1, were considered in *Car Equipment*, Part 3. The diagram is here reproduced for convenience. It was also shown that the effects resulting from a ground at any point between these letters are very similar. The position of such a ground can be still further located by the action of the car when the reverse switch is thrown to the dotted position. If the ground takes place between the rheostat and post *5* on the reverse switch (that is, on the rheostat itself, on the field coil, on the three-point part of the reverse switch, or on any wire connecting these devices), no matter in what position the blades of the reverse switch may be put, it will be impossible to move the car, because throwing the reverse switch does not alter the position of the grounded part. The fault does not, in this case, move with the reverse switch, so that, whatever may be the position of the latter, the current still takes the short path to earth through the



For notice of the copyright, see page immediately following the title page.

fault instead of going to earth through the armature. If, however, the fault takes place on the two-point side of the reverse switch, on the $A+$ side of the armature, or on any wire between these two parts, the fact can be found out by

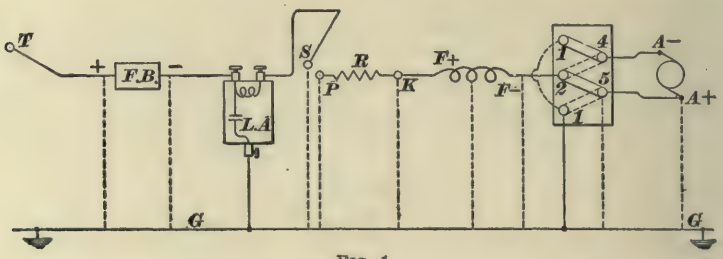



FIG. 1.

throwing the reverse switch and trying to start the car. If the car fails to move, although a flash at the rheostat shows a current to be flowing, the fault must lie between $R$ and point *5* on the reverse switch; if, however, the car backs up all right, it goes to prove that the fault is on or between points *5* and $A+$.

The reason the car will back up but will not go ahead, when a fault occurs at any of the points named, is this: For either position of the reverse switch, one side or the other of the armature is grounded by means of the ground wire running to posts *1*, *1*, which are connected as shown by the dotted line. In the position shown in Fig. 1, the ground wire is connected, by means of posts *1*, *1* and the switch blade *1–4*, to post *4*, which connects to the upper side of the armature. When a fault occurs at $A+$ or post *5*, the result is to put a ground on both sides of the armature, thereby short-circuiting it, so that it cannot get any current with which to move the car. In other words, the intentional ground or permanent ground is on one side of the armature, and the accidental ground or fault is on the other side. If the reverse switch is thrown over to the back-up or dotted position, the effect is to throw the permanent ground to the lower *1* post, instead of the upper *1* post, with the result that the permanent and accidental grounds are put on the

same side of the circuit, where the fault cannot be felt, because, since the ground wire already grounds that side, the effect of the fault is simply to increase the size of the ground where it is most wanted.

**2.** The fact that it is possible for a car to be so grounded that it will go ahead but will not back up, explains why it is that, on roads having a loop on the end, cars will run day after day from one rheostat with no trouble at all; but when an attempt is made to run the rheostat at the other end of the car, a ground shows up. A loop replaces a turntable, and is a continuous curve by means of which a car runs around to return on the same track, or one parallel to that on which it came up; the direction of the car changes, but the front end remains the same and the crews do not change ends. When a double-end car is run from but one end for a long time, the reverse switch may possibly remain unchanged for days at a time, so that a fault might develop on the grounded side of the armature and not be found out. Now, in going from one end of a car to the other end to run it, it is necessary to throw the reverse switch, because, since the direction of motion of the car is changed, it amounts to the same thing as backing it up from the original end. As soon, then, as the reverse switch is thrown, those faults that remained unnoticed so long as they were on the same side of the armature as the permanent ground, assert themselves and give trouble.

**3. Shifting Brushes.**—Another source of trouble incidental to running cars around a loop is the following: On old-style dynamos and motors, at one load the brushes were in a certain position; as the load increased, it was found necessary, in order to avoid sparking at the brushes, to move them forward—that is, around in the direction of rotation, on a dynamo, and backwards, or opposite to the direction of rotation, on a motor. As the dynamo and motor became better known and more nearly perfected, it was found possible to build them so that the brushes could be left in one

position from no load to full load, and even to overload without excessive sparking at the brushes. Even at present, on the most up-to-date machines, there is bound to be some sparking at the brushes if too much load is put on. Now, no machine in the world is subjected to greater abuse in the way of overloads than a street-car motor; every time it is started, if it is not started rightly, and this is the case more often than not, the motor gets more than its load, and, if too much more, there is some sparking. If it were practicable to rig up some means of shifting the brushes backwards, the sparking could be largely done away with; but there are a great many good reasons why such a scheme would be bad.

It is easy to see, then, that, since shifting the brushes on a street-car motor cannot be done readily, and, since the car, and therefore the motor, must be able to run in both directions, the brushes must be centrally located, so that, within certain limits of load, they will not spark for either direction of rotation. When so set, they will spark some, under excessive load, going in either direction. If, however, a car has a rheostat on only one end, and reverses its direction of motion by running over a Y or around a loop at the end of the road, the motor runs in one direction all the time and the brushes can be set to suit this direction. The brushes will then be a long way out of position for the opposite direction, so that in backing up not over half of the rheostat should be cut out, because the brushes will spark badly; also, if the brushes have been set over to suit single-end control, they should be set back to the central position if the car is ever converted into double-end control.

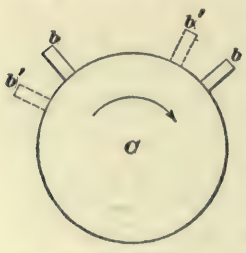


FIG. 2.

**4.** Fig. 2 illustrates what is meant by shifting the brushes. *C* is a circle indicating the outline of the commutator, and the arrow shows the direction in which the armature is supposed to turn; *b*, *b* are the two brushes set in their normal position to suit both directions of rotation, and *b'*, *b'* show the brushes set back

to suit the non-sparking requirements of single-end control. The permanent setting back of street-car-motor brushes is a bad practice, unless the person doing it knows exactly what he is about. Most car-motor brush holders are designed to hold the brushes in the position in which they leave the factory, and it takes a great deal of extra work to change them.

**5. Grounds in Armature.**—In connection with Fig. 1, the effects of all grounds possible to occur anywhere from the trolley wheel $T$ to the positive side of the armature $A+$, inclusive, have been considered. Now, if a ground takes place within the winding of the armature itself, the symptoms are very different. Since the armature turns round, any ground that occurs on it turns round also, and constantly

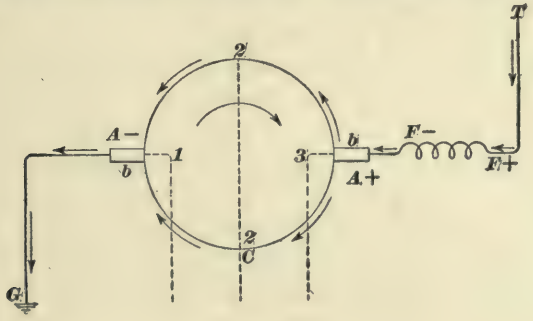



FIG. 3.

shifts its position and thereby its relation to the permanent ground on the negative side of the armature. Fig. 3 will help to show more clearly why this is the case; it shows very plainly that the negative brush is permanently grounded, and the natural course of the current when the armature is all right is shown by the arrowheads. When the current gets to the armature, it divides into two parts, one part going through the upper half of the armature, and the other through the lower half; they meet again at the negative brush and flow together to the ground. Suppose a ground to occur on the armature; when it gets opposite the negative

brush at the position marked *1*, it can have no effect, because it is in contact with the brush that is already grounded, and the condition of the armature is not changed; when the armature turns and brings the fault to position *2*, the current passes through a part of the armature and the armature has some turning power, but the rest of the armature is short-circuited by the fault. When the fault reaches position *3*, it is in contact with the positive brush where the current enters, and, consequently, short-circuits the armature entirely, robbing it of all power to turn. As a result of these various effects, the armature, if it can be made to run at all, runs with a very jerky motion. On a single-motor equipment, such as that now under consideration, the armature probably will not run at all unless the car is in some way given a start; but in double-motor equipments, the good motor furnishes the power to run the car, and the bad one can kick up as much as it pleases. The fact that a motor runs with a jerk, though, does not necessarily mean that the armature is grounded. An armature may become short-circuited in such a way as to cause these same symptoms, and yet have no part of the copper wire on the core in contact with the iron core itself. When an armature runs with a jerky motion, and it is desirable to find out if it is short-circuited or grounded, disconnect the ground wire and throw the rheostat on and off; if the armature is grounded, there will be a flash every time the rheostat is thrown off, but if it is short-circuited, there will be no flash. A short-circuited armature on a single-motor car is much more apt to have starting power enough to start the car than a grounded one. If a short-circuited armature is allowed to run for any length of time, it will get so hot in some places as to burn all the insulation off the wires.

**6.** Grounds occurring between *A*—, the negative side of the armature, and the ground can cause no bad effect, because that side of the armature is already grounded and cannot be any more so. What makes such a vast difference in the effects of grounding the positive and the negative sides of

the street-car motor is this: When a ground occurs on the positive side of an armature, the current goes to the ground without reaching the armature, and the latter can do no work; whereas, when the current gets to the negative side of the armature, its work is done.

### FIRST AID TO THE CRIPPLE.

**7.** Now, to sum up the various results of grounds considered in connection with Fig. 1. It must be borne in mind that a single-motor equipment is much more helpless in time of trouble than a double-motor equipment, because in the latter there is always one motor to run on. However, in connection with the single-motor car, there are a few things that can happen that need not make the car helpless, but they are apt to do so unless the motorman knows his business. Of course, for the present, only troubles due to grounds are to be talked about. If a car for no apparent reason loses the power, it may be due to any one of several causes: the line may be dead; the rail may be dusty; the pole may be off; or the main-motor fuse may be blown. Without going into the details of these several conditions, we will suppose that an inspection shows that a fuse has blown. Sometimes fuses blow because they are old or because they have become loose in their fastenings, but in this particular case we will suppose the fuse to be blown because of a ground.

*Ground on Fuse Box.*—A ground on the fuse box happens comparatively seldom, and may be remedied by cutting loose the two wires from the fuse box and joining their two ends together by means of a third piece of wire, unless the ends of the two wires are long enough to connect without a third piece of wire. If a third piece of wire must be had and there is none on hand, cut the ground wire out of the lightning arrester, and use it for splicing the fuse-box wires together; if a long piece of wire is needed, take the shunt or loop wire where one is used. In any case, report the matter as soon as possible to the inspector or barn boss.

*Ground on Lightning Arrester.*—If a ground occurs on the

lightning arrester, its effect can generally be done away with by cutting the arrester ground wire.

*Ground on Rheostat.*—If a ground occurs on the rheostat and a careful inspection shows that it cannot be removed, the only thing to do is to disconnect the rheostat entirely from the circuit by taking out the wires that run into *S* and *K* (Fig. 8, *Car Equipment*, Part 3), as well as the wire running into *L*, if there is one. Then join the two wires *S* and *K* together by means of a third piece of wire, and run the car to the house by means of one of the hood switches.

*Ground on Motor Fields.*—If a ground occurs on one of the motor fields, the faulty field, if it can be located, can be disconnected, and the car run in on the remaining field or fields. To say "disconnect a field" sounds easy enough, but the job of disconnecting a field is harder for several reasons than it ought to be; the details of the operation will be talked about in another part of this Course.

*Ground on Reverse Switch.*—If a ground occurs on the reverse switch, or on any wire running to the three-point part of it, make a careful inspection to see if the fault can be removed by lifting, tying up, or changing the path of the wire that is giving the trouble. If the fault is on the switch itself and cannot be removed, the switch may be cut out as follows: Disconnect wires *F*— 2, and *A*+ 5, Fig. 1, and connect them together; when this is done, the reverse switch is, of course, useless, and the car cannot be made to back up, but it will go ahead all right, and should be run to the house and its condition reported.

*Ground on Brush Holder A+.*—If a ground occurs on post 5 or on brush holder *A*+, the condition is indicated by the fact that the car can be made to back up, but not to go ahead. In other words, the ground will allow the car to run but one way; if this one way can be made the right way, the car will be in shape to run to the house. The grounding of brush holder *A*+ is an every-day source of trouble. If the armature lead going into post 5 is made to exchange places with the lead going into post 4, the effect is to put the fault on the same side of the armature as the permanent ground; also,

the field leads should be renewed. The current now enters the armature at the top brush holder, Fig. 1, instead of at the bottom brush holder, with the result that the car will run only in the forward direction, and can be run to the house. It must, of course, be borne in mind that when any change, such as the above two, is made, the car cannot be reversed; and the motorman, having only his brake to fall back on, in case of an accident, must run with great care and always keep his car under perfect control. It should be almost unnecessary to say that the above changes are temporary ones, made just to enable the car to run to the house.

### FIELD NEXT TO GROUND.

**8.** In all the figures shown up to this time, the armature has been the part reversed in order to reverse the car, and, as such, has always been placed next to the ground. Now this is not always the case; on some roads it is the field that is reversed, and, in such a case, it is placed next to the ground. As far as the merits of the two cases go, one custom is not much, if any, better than the other, although there are arguments in favor of both. We will not take up at present the relative advantages of the two connections; but, as the order in which the armature and field occur in the circuit has very greatly to do with how a car will act if any part of its wiring system becomes grounded, the field-next-to-the-ground plan will be talked about only just so far as it may affect the action of a car.

**9.** Fig. 4 is the same as Fig. 1, except that the field is next to the ground and a shunt or loop cannot be conveniently used in conjunction with the rheostat. Up to point $K$, the effect of a ground is about the same as when the armature is next to the ground, and the means of helping the car out are also the same. A ground in the armature itself, or, in fact, anywhere on the circuit between $A+$ and $F+$, will cause more violent effects, and be apt to do more damage, on account of the resulting fireworks, than it would

in the case of Fig. 1, because a ground anywhere from $A+$ to $F+$ cuts out the field winding entirely, and the armature, having no field, can have no counter E. M. F., and, therefore,

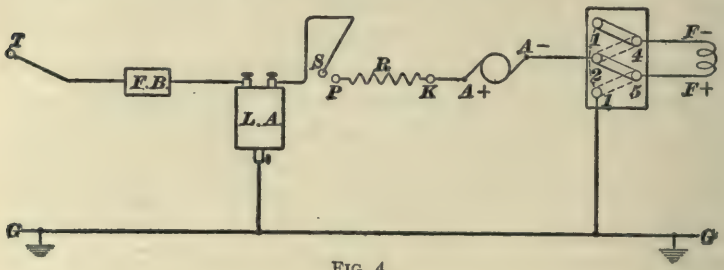



FIG. 4.

admits a very large current that may do much damage before the main-motor fuse is blown. This fact forms the basis of one of the good reasons advanced for putting the armature next to the ground. Of course, when the field is not next to the ground, it stands more chance of being hurt by excessive flows of current due to faults, and fields are more expensive to repair than armatures. On the other hand, as the armature turns while the field does not, its injury is apt to be more severe. A ground on post *5* or field lead $F+$ or on any wire or connection in between them, will, of course, make it impossible to run the car ahead, but it can be run back. In order to fix the car so it can run ahead and not back up, the leads going into the armature must exchange places. A fault between $F-$ and $G$ can do no harm until an attempt is made to back the car up, which, of course, cannot be done. On single-motor equipments, the plan of Fig. 1 is the best, because the armature is not so liable to injury. One bad armature disables a single-motor car, but one bad field leaves one or three fields to run in on.

---

### A GROUND ON THE LOOP WIRE.

**10.** Fig. 5 is a diagrammatic sketch to make the effect of a ground on the loop wire more easily seen. Since the loop wire is permanently attached at one end to a part of the

field coil, it is evident that a ground on the loop would have the same effect as a ground on the field coil at the point where the loop wire is tapped on. This effect we know from

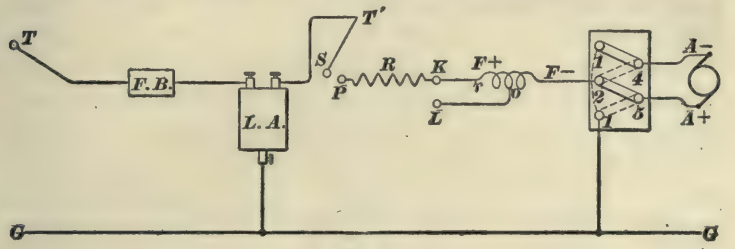



FIG. 5.

a previous article to be as follows: If the fault occurs while the car is in motion and the loop wire idle, the speed will be suddenly checked; because the part of the field coil included between $F+$ and $o$ becoming separately excited, and both brush holders being grounded—one by way of the fault and the other by way of the ground wire—the sudden drag on the armature gives the headway of the car more work than it can do at that speed, even though the car is going down hill, and the speed is pulled down. The higher the speed of the car when the ground occurs, the more severe will be the bucking, because the higher the speed, the higher the E. M. F. that the armature can generate, and hence the more current it can send through the short circuit.

**11.** If the fault on the loop shows up while the loop wire is in action, the effect is the same as if the ground were on $K$: the excess of current blows the motor fuse; and, if the car is on a level or is going up a grade, the check in the speed, due to the loss of the power is felt. There is, however, no decided bucking, because the current passes from $K$ through the rheostat shoe $S$ to $L$, and from $L$ along the loop wire to the fault, through which it passes to the earth. There can be no decided bucking, for, since the current does not pass through any part of the field in order to get to the fault, there is no separate excitation, and hence no dynamo action on the part of the armature. If the fault occurs while the

car is standing still, it will be impossible to move the car; for, although the loop wire is not in action, still one end of it is permanently attached to the field coil at *o*, and no current can reach the armature. If *S* is moved far enough around on *R*, the main-motor fuse will blow. It may be some relief to know that the grounded loop wire and its bad effects can be entirely put out of the way by disconnecting the wire at *o* and at *L*. That part of the field coil included between *F*+ and *o* is the part that is cut out when the loop wire is put in action, and is a part of the loop proper; but a ground on this part of the field coil is, in effect, no different from a ground on any other part of the field, except that the nearer to *F*— the ground occurs, the more field will the short-circuit current separately excite — hence, the more violent will be the bucking.

---

### A GROUND ON THE SHUNT.

**12.** Fig. 6 is a diagrammatic sketch of the shunt connections. If a ground occurs on the shunt while the car is in motion, and the shunt is in action, the effect is the same

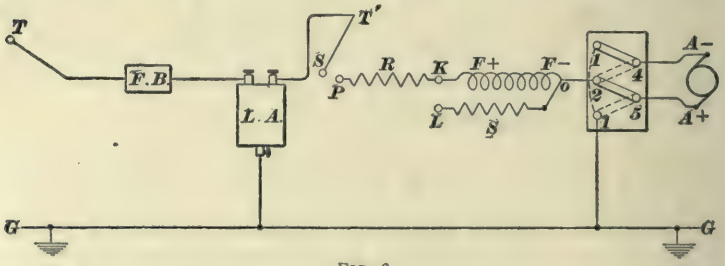



FIG. 6.

as in Art. **11.** If the ground shows up while the car is in motion, but while the shunt is not in action, the effect is the same as in Art. **10,** but the bucking is apt to be more violent, because, since the shunt wire taps on to the end of the field coil, instead of in the middle, as the loop wire does, the whole coil becomes separately excited, instead of only a part of it, as in the case of the loop wire. If the ground occurs

while the car is standing still, the effect is the same as in Art. **11.** In any case, the grounded shunt and all its troubles can be put out of the way by disconnecting its wires at *L* and *o*; the fact should be reported to the barn boss.

---

### OPEN CIRCUITS.

**13.** An open circuit on a single-motor car is a very simple problem to deal with from an electrician's point of view, for he has a very simple device with which to locate it. A motorman is not supposed to know anything about these devices, and his field of inquiry is limited largely to inspection and to a careful observation as to how a car acts on account of the open circuit. As an open circuit in any one of several places gives symptoms exactly alike, very few true conclusions can be drawn from the way a car acts. Inasmuch as it is very possible that a motorman may not always be a motorman, especially if he knows enough to be something better, it is proposed, at the end of this Course, to devote at least a part of a Paper to such simple and quick tests as barn men are accustomed to use in locating grounds, open circuits, and such like. In the present Papers, the practice of drawing conclusions from the action of the car will be adhered to.

**14.** Fig. 1 is a plan of the wiring for a single motor with neither a loop wire nor a shunt. Fig. 5 is a plan for the same wiring using a loop; and Fig. 6 is the plan when using a shunt. In all three plans, up to plate *P*, there is no way of telling in what part from *T* to *P* the open circuit lies. The car fails to move even if the shoe *S* is put around to plate *K*, and it acts the same for any point between these limits. Inspection alone can locate the fault. The same can be said of an open circuit between points *F*+ and post *2*, and between points *F*— and post *4*; also, between post *1* and the ground. A careful inspection will often show that the failure of the car to start on any of the positions of the rheostat is due to any of the following causes:

**15. Trolley Pole Off the Wire.**—This may sound like a very foolish and improbable cause, but, as a matter of fact, two cases are on record where the pole flew off the wire, and, the crew, thinking, if they thought at all, that the power was off the line, went inside the car and sat down to wait for it to come on again. They left the controller on the first notch, so that the car would start up as soon as the power should come on again. In another case, the crew stayed in the car (it was a cold day) until a boy told them that the pole was off. In another case, the crew went to sleep and did not wake up till the crew on a car going the other way waked them. Of course, the power was at no time off, for, had it been, the second car would not have been able to run. In order to find out if the power is on or off, be sure that the pole is on the wire and turn on the light-switch; if the lights burn, of course the power is on; but if the lights do not burn, it is by no means certain that the power is not on, because the lamps may fail to burn if the lamp circuit is out of order. There may be a bad lamp, a lamp loose in the socket, a blown lamp fuse, a broken wire, or a lamp switch out of order, or there may be so much dust on the rails that even the small lamp current will not go through it. As a rule, if the lamps fail to burn, the cause will be found either in a lamp or in the lamp-circuit ground wire. Light-circuit trouble can almost always be found by inspection.

**16. Trolley Wheel on Circuit-Breaker.**—The car may have been stopped in just such a place that the trolley wheel rests on a line circuit-breaker. In such a case, the pole can be swung around ahead, the car run up a little till the wheel clears the breaker, and the pole then swung around behind again. These line breakers are put in to cut the line up into separate sections so that a ground on one part of the line will not tie up the whole road. They are especially useful on both sides of an iron bridge, for here, more than anywhere else, grounds are liable to take place. The position of these line breakers should always be marked by a signboard, and motormen should see that the power is off when crossing

them, for the sudden breaking and closing of the circuit not only hurts the motors, but the arc caused by opening the circuit hurts the breaker itself and shortens its life.

**17. Insulated Trolley Pole.**—One cause of open circuit, and one that occurs only once in a long while, is due to a change of poles. If, in painting a pole with japan or asphaltum, a very thick coat is put on the base of the pole, the current cannot work its way through it; and in such a case, the car lights will not burn. This fault is one that occurs so seldom that it is apt to be hard to find it when it does occur. The main clue to it lies in the fact that, if the car ran along all right before the pole was changed, and would not run at all after the pole was changed, the fault must in some way be connected with the pole.

**18. Break in Main Trunk Wire.**—A very common source of open-circuit trouble is the breaking off of the main trunk wire from the trolley base. This is one of the first places to look for trouble, and it is especially apt to be the place if the trolley bridge has just sustained a jar of any kind. The next place that is apt to give trouble of this kind is one of the hood switches; one of them may be open, or it may fail to close the circuit when it is put on. The reason for this is that the constant throwing on and off of the switch causes so much arcing that the switch blades, in course of time, become coated with a surface of very hard oxide of copper, and this will not let the current pass to the spring contact plates. Open circuits due to this cause do not occur very often, but when they do, they are not easy to find. If there is any reason to think that the switch is out of order, take one of its wires out of the post and hook it over the second wire; if the car then starts all right, the trouble must be in the switch.

**19. Blowing of Main Fuse.**—An every-day source of open circuit is the blowing of the main-motor fuse. The blowing of a common fuse can be heard, and at night the

flash is easily seen; but on an up-to-date magnetic blow-out fuse, there is very little show of any kind. Sometimes, when a fuse blows, it burns the thumbscrews so badly that a new fuse cannot be put in. In such a case, the two ends of the fuse wire may be twisted around the posts into which the trunk trolley wire runs. If these posts are also disabled, the two ends of the trunk wire may be knit together with a fuse wire.

**20. Open Contact at Rheostat Shoe.**—An open circuit may be due to the fact that the rheostat shoe does not make contact. The shoe may be loose, or it may be lost, or the bolts in the frame of the rheostat may have become loose and let the frame shake about so as to loosen the arm holding the shoe.

**21. Loose or Broken Wires.**—Of course, it goes without saying that the open circuit may be due to a loose or broken wire or connector. It often pays well to inspect all wires going into and out of the trolley base, fuse box, arrester, motor, reverse switch, and rheostat. These wires may sometimes seem to be all right, and yet at the same time be broken inside the cover. A wire may be out of the two-way sleeve or connector, and still be held in its place, as far as one can see, by the tape wound around the joint. To be sure that there is no loose joint in the wire, work it up and down. A very common source of open circuit—one that occurs every day on a road that runs two or three hundred cars—is the working loose or breaking of the ground wire. If the job is well done, a car should have a ground wire running to at least two points on the single motor, and each of these ground taps should be made of at least a No. 4 stranded cable. A cable is a wire made up of several small wires, and is much safer than a solid wire of the same cross-section, because a bundle of small wires is much more flexible than one large solid wire, and is much less liable to break off, since it takes up the spring and jolting of the car.

**22. Dusty Rails.**—In the summer time, when there is a great deal of dust on the rail, a car very often will not move ahead when the power is again put on, after it has been stopped in a dusty place, because the dust is so thick between the wheels and the rails that the current cannot get to the rails. A car will keep on going through much thicker dust than it will start in after it is once stopped, for if the power is on when the car strikes the dust, each wheel is trailed by an arc through which the car gets current enough to run it. When a car stands on so much dust that it cannot start, it is a very dangerous thing for a person standing on the ground to fool with. Standing on the dust and insulated from the rail by the dust, the car is charged, and will send a current to the ground as soon as there is any path to send it through. A person standing on the rail and touching a brake handle, grab handle, or fender, offers just the path the current is looking for, and through his body it goes, giving him a very unpleasant feeling. The car can give a shock whether the rheostat is on or not, for the first thing a crew is taught to do, when it is thought that the car is *grounded*, as they say, is to turn on the light-switch to see if the lamps burn, and, as a rule, they leave the switch in so as to tell when the power comes on again, in case the fault is due to want of power on the line. If there is good reason to think that the fault is due to the dust, the right use of a switch iron will soon remove all doubt. Take a switch iron and scrape along the rail, jam it up between the wheel and the rail; in doing so, be very sure to make good contact with the rail before letting the switch iron touch the wheel, or a bad shock is sure to follow. The reason is that, if the switch iron touches the wheel and does not touch the rail, the current goes along the iron to the hands and thence through the body to the rail. The best way to do the job is to have some one hold down the pole from the wire till the iron is in place; then there is no chance of getting a shock.

To know how to charge a car is once in a while of as much use as to know how to get rid of a charge. In some of the large street-car repair shops where cars are built, it is almost

out of the question to stand a completed car outside of the house, because the small boys not only deface the fresh paint and break the glass, but they steal every piece of brass or copper that they can lay their hands on, even to the check-plates and brasses, and the wire cable under the car. If a car is well charged, no one can lay a hand on many parts of it that are most apt to be touched without getting a severe shock. To charge a car properly, clean the rail well just about where the car wheels are going to rest; place four pieces of paper so that one car wheel can be run up on each piece. As soon as the weight of the car is on the papers, tear away all that can be seen of them. The car had best be run up on the paper by hand, for, if the power is used, as soon as the wheel goes up on one of the papers, an arc is set up that is likely to set the paper on fire and ruin the job. The purpose in cleaning the rail before placing the paper is to get rid of any rough particles that might puncture the paper as soon as the pressure of the wheel begins to act. To complete the job, the pole is put on and the light-switch turned on; the rheostat is left off. The lights cannot burn because there is no ground. On six or more well known roads, all motormen, before they can be turned in, are put through a sort of practice drill that includes the task of finding out what is the matter with a car that is all right except that the lights will not burn, and that cannot be made to move.

**23. Open Circuit at Brushes.**—The failure of a car to start is sometimes due to the fact that one of the brushes may have been left out altogether; in such a case, the current cannot get through the armature. A piece of wood or rubber insulation may have become wedged between one of the brushes and the commutator; this sometimes happens when the carpenters or trimmers work inside the car with the trap doors up, or when one of the electricians, in skinning the cover off a motor lead, happens to drop some of the chips down on the commutator; in such a case the car would run, could it but once be started, because the turning of the commutator would soon eject the piece of foreign matter.

A brush hammer may have been left up so that the brush spring cannot press the brush down against the commutator. The brush may be too thick for the brush holder, and not reach the commutator. Sometimes a brush may seem to be all right when it is put in, but if the upper end is thicker than the lowor end, the brush will stick as soon as it wears down far enough. On account of this fact, it is well, when putting in a brush, to turn it end for end and try it. It may be all well and good to have a gauge in which to gauge the brushes before they leave the storeroom, but this does not insure the brushes going into a brush holder that is a little below gauge or that has received a blow to bend it slightly out of shape. A brush should not be a snug fit in the holder, for some brushes, especially those having a great deal of grease in them, swell when they get hot, and the paraffin oozes out, with the result that very soon there is a coat of paraffin and carbon dust all over the surface of the brush that causes it to heat for want of contact. If a brush is too thick for the holder, the best thing to do is to get a thinner brush. The practice of sandpapering a brush is not a good one, because it takes all the copper coating off, impairs its surface contact, and causes the brush to heat, so that it soon becomes a source of trouble.

---

### DEAD RAILS.

**24. Effects of Poor Bonding.**—One of the most annoying and most dangerous sources of open circuit is a dead rail. It is annoying because it is one of the last things thought of even by those in a position to think of it at once. It is dangerous because, as will soon be seen, it can very easily be the cause of a severe shock to a person or to an animal. Every old motorman knows, or thinks he knows, that the line wires bring the current from the power house to the car, and that the rail takes the current from the car back to the power house. Now, the joints between the rails soon get rusty, and, when they are so, they do not carry the current very well—in some cases, not at all. In order to improve

the joints electrically, it is customary to join the rails together with a piece of wire called a *bond wire*, or, briefly, a *bond*. Now, the constant jolting and jarring that the rails get, due to the pounding of the heavy trucks, will, in course of time, work these bonds loose.

Again, out in the country district, where the rail is generally T rail, and therefore very much exposed, the copper bond wires are very much of a temptation to thieves, who sometimes even follow the workmen at a safe distance and cut out the bonds about as fast as they can be put in place.

**25.** Fig. 7 shows the path of the current from the power house out to the car, through the car, and back to the power house by way of the rails *c*, *b* and their bond wires, one of which is shown at *d* by the dotted line. *A* is the dynamo in

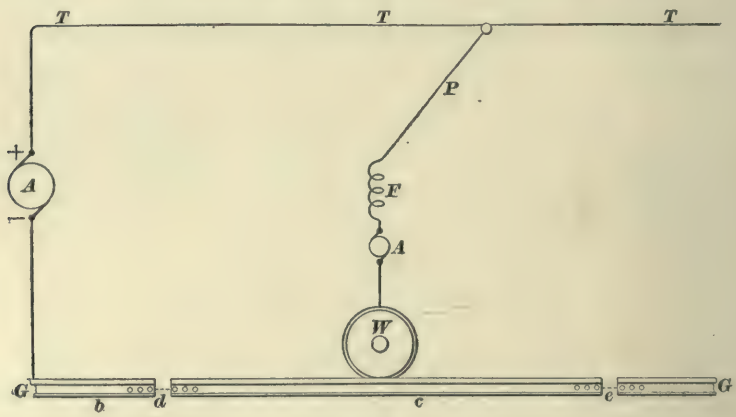



FIG. 7.

the power house; one side of *A* goes to the trolley wire *T T*, and one side to the rail *G*; *F* is the car-motor field, and *A* is its armature; *W* is the car wheel through which the current must pass in order to get to the rail. The path of the current from the power house to the car and return is *A*+–*T*–*T*–*P*–*F*–*A*–*W*–*c*–*d*–*b*–*G*–*A*–. If the bond *d* is cut out or broken, it is easy to see that the current cannot pass from rail *c* to rail *b*. Rail *c*, under this condition, is called a *dead*

*rail*, but it is very much alive when a car stands on it, and all that is necessary for man or beast to get a shock is to make connection in any way between rail *b* and rail *c*. Every street-car track, of course, has two lines of rail, and the rails on the two sides are always bonded, but the two sides are not always bonded together.

Fig. 8 (*a*) and (*b*) shows two ways of bonding rails. In (*a*) not only are the rails on each side bonded together, but a wire zigzags down between the two lines of rails and connects all the bonds together; when a road is bonded in this

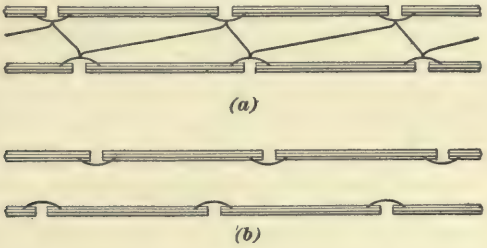



FIG. 8.

way, it is very unusual for the rails to become so dead as to interfere with the running of a car. Fig. 8 (*b*) shows the simple mode of bonding used in most cases; even in this mode, in order that a car may become dead railed, there must be a dead rail on both sides of the track. If the track is a single one running out into the country, and with no other trolley track or steam track crossing it, the chances are great that, on a very dry day, no cars will be able to get power enough to run on that side of the dead rail which lies away from the power house. On up-to-date roads, a dead rail with such serious consequences rarely, if ever, occurs, because, in the first place, the rails are well bonded together, and even where there are several tracks, all lines of rail are connected together. Besides this, there are usually cross-rails and water pipes to help the current back to the power house.

**26.** When a track is bonded as shown at (*b*), Fig. 8, it is not at all necessary that the two dead rails occur opposite each other, for, since the two lines of rail do not touch each

other, a dead rail anywhere in either line of rail will make that line of rail, which is out beyond the break, dead. In case a motorman has reason to think that he has a dead rail on his hands, he can soon find out by taking his switch iron and forcing it down between the dead rail and the one next to it. The switch iron acts as a bond wire and completes the circuit so that the car can run. As a rule, when a car gets stuck on account of a dead rail, it is not due to the breaking of one or two bonds, but is the added-up effect of several broken bonds; the last one passed over is, so to speak, the straw that breaks the camel's back. A great deal more could be said on the subject of dead rails, but as it would involve a discussion of facts that we are not yet able to prove in a simple way, it will be left out of this Paper.

---

### OPEN CIRCUIT IN THE ARMATURE.

**27.** It makes no difference whether a loop or a shunt is or is not used; the action of a car is just the same in the one case as in the other, when there is an open circuit in its

FIG. 9.

armature. A ball of fire runs round the commutator from one brush to the other. In order to see clearly why this is so, Fig. 9 is given to show how an armature is made; in this figure, *1*, *2*, *3*, *4*, *5*, *6*, *7*, *8* are the bars of the commutator.

and $C_1$, $C_2$, $C_3$, $C_4$, $C_5$, $C_6$, $C_7$, $C_8$ are the coils whose ends are brought down and connected to the bars; two ends go into each bar, so that the bars serve the purpose of connecting the ends of the coils together and making them into a continuous winding. In Fig. 9, *b*, *b'* are the brushes, and $A+$, $A-$ are the armature leads; coils $C_1$, $C_2$, etc. are wound on the iron core, and their ends, called *coil leads*, are left long enough to reach the ear of the commutator bars; two of these leads go into each bar, as indicated in Fig. 9. To receive the leads, the bars are slotted, and the ends go into the slot—one on top of the other, and not side by side as shown in Fig. 9—which is drawn for the purpose of showing clearly the path of the current as it goes in and out of the armature. The current goes into the armature by way of lead $A+$ and brush *b*; leaving the brush, it splits into two parts, one half going through the upper part of the armature and the other half through the lower part.

**28.** It can be seen that even if the armature has one open circuit in it, the current can still find its way through the other half. In other words, the brushes divide the armature into two paths, either of which can carry a current whether the other half does or not. Suppose an open circuit to exist in coil $C_4$ at the place marked *a*. In the position shown, the upper half alone carries its share of the current; the lower half takes some current because there is an arc set up between bars *4* and *5*, and some of the current must be going over from one bar to the other, or the arc could not keep up. The reason the arc is able to keep up is as follows: When bars *3* and *4* are under the brush, the brush, of course, makes a contact between them, and bar *4* carries a current; that is, at the moment that these two bars are under the brush, the brush short-circuits the bad coil whose ends go to these bars, and, since the bad coil is not in the circuit, its effect cannot be felt.

So long, then, as the bad coil is under either brush, it can show no bad effect; but, since the bad coil, most of the time, is not under the brush, its effect can be seen in the

spark that runs round the commutator. The passing of the bar from under the brush breaks the current that the bar carries, and sets up the arc; as soon as the arc is set up, the voltage generated by the coils in the bad half of the armature is large enough to maintain the arc, and this arc is the spark that is seen to run around from brush to brush on the commutator. An open-circuited armature will run with a jerky motion if it will run at all. As a rule, the open circuit will be found to be due to a broken coil lead or to a broken wire inside of the commutator. (Some street-railway commutators have wires inside of them, but such commutators are on motors that have long been out of date.)

---

### OPEN CIRCUIT IN THE FIELD.

**29.** How a car will act when its single motor has an open-circuited field, and what is best to do when such is the case, depends, to some extent, on whether the motor has a shunt or a loop or neither. If the plan is the straight full field, such as shown in Fig. 1, the circuit is dead open, and the car cannot be made to move until the break is done away with. If a careful inspection shows in which coil the fault lies, the faulty field can be cut out and the car run home on the good ones. Figs. 10 and 11 show how the field leads on most motors are brought out of the motor frame. Figs. 12 and 13 show how the field leads are brought out on a few motors. Fig. 10 is a motor with but two field coils—a top coil and a bottom coil. The four field leads are brought out through holes in the motor frame; these holes are bushed so that the lead cannot be hurt by rubbing on the edge of the hole. Two of the leads come out of the rear of the motor, and are

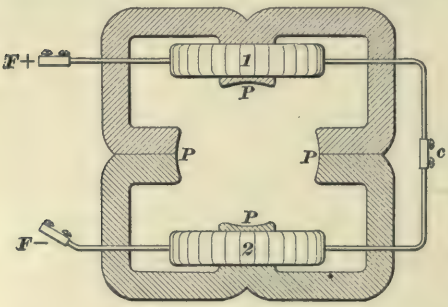



FIG. 10.

joined together by means of the two-way connector $c$; the other two leads come out of the front of the motor, and, by means of two-way connectors, join to the car wires leading to the reverse switch and to plate $K$, Fig. 1.

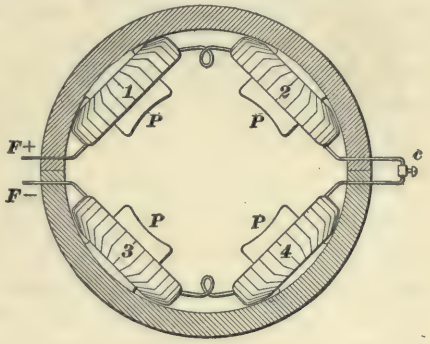



FIG. 11.

**30.** Suppose an open circuit to occur in one of the coils; to find out in which coil it is, inspect the motor, for very often the fault is due to a burnt-off lead. If the trouble cannot be seen, proceed as follows: Separate the two fields by taking one lead out of connector $c$; next take the car wire running into $F-$ and join it to the top field lead that has been taken out of $c$. The net result of the change is to cut out the bottom field entirely, so as to try the top field alone. If the car now fails to start upon putting the rheostat on, and there is no flash when the rheostat is thrown off, it goes to prove that the bottom field must be the good one. The next step is to try it alone; to do this, place the car wire going into $F+$ into sleeve $c$ instead of the top field lead that was taken out to make the first test. It must be borne in mind that the effect

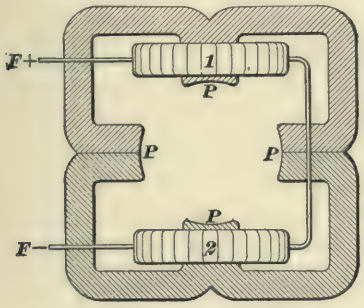



FIG. 12.

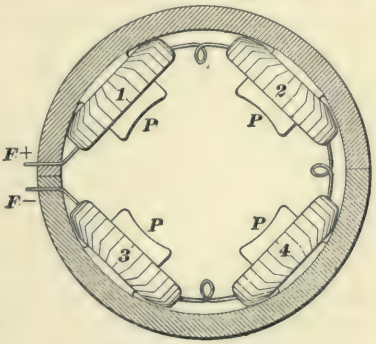



FIG. 13.

of cutting out one field coil is to make the starting power of the motor much less, and, to start the car, the rheostat shoe will have to be moved farther around than it would were both field coils in use. The maximum speed of the car, however, will be greater, and if the motor has a shunt, it should not be used.

**31.** If the two fields are joined together inside the motor, as shown in Fig. 12, it will, perhaps, be impossible to get at the joint to break it. In such a case, the only thing to do is to wait for the next car to shove the cripple to the house. What has been said of Figs. 10 and 12 is true also of Figs. 11 and 13. Where there are two top fields and two bottom ones, the top ones are joined together and the bottom ones also; so they may be treated just as if there were one top and one bottom field. It is, of course, to be understood that the practice of cutting out a field is resorted to only as a means of enabling the car to run into the near est depot. If the car is run for any length of time with a field coil cut out, the good fields, the armature, and the rheostat are all very apt to show the effect of it. What has been said above refers to a car running without a loop or a shunt, the plan being that shown in Fig. 1. In cases where there is a loop or shunt, some further symptoms are likely to appear, and further precautions must be taken.

---

### OPEN CIRCUIT ON A LOOPED FIELD.

**32.** Fig. 5 is a plan of the car wiring when the motor has a loop in use. The loop wire comes into action as soon as the shoe $S$ touches the plate $L$. When the loop wire is in action, that part of the field coil marked $r$ is cut out, and might just as well not be there, so far as being of any use is concerned. In other words, if, while the shoe is on plate $L$, the wire going into plate $K$ from the field, is cut, it will make no difference in the running of the car, because no part of the wire or of the field coil between points $K$ and $o$ is being used. An open circuit between $K$ and $o$ will cause

the car to act as follows: If the fault occurs while the car runs on the loop, it will have no effect at all; but as soon as it is tried to start the car from a standstill, it will take no power till the loop position is reached, when it will start with a very sudden jerk, because there is no resistance in the rheostat.

**33.** If an open circuit occurs between the loop tap *o* and the reverse switch, the car cannot be started at all until the fault is removed. In case of an open circuit between *o* and *K*, the best way to get the car home is to take the field wire out of plate *K* and coil it up so that it cannot drag on the ground; then take the loop wire out of plate *L* and put it into plate *K*. The effect of this change is to make the car start with the rheostat in circuit. It will not start as soon as the shoe touches plate *P* (if the rheostat is a new one, for new rheostats have more resistance in them than old ones), because the cutting out of one coil makes the starting power of the car so much less that it will not start until the shoe gets far enough around to let the current become sufficiently large to make up in amperes what has been lost in turns. If an open circuit occurs between *o* and the reverse switch, the first thing to do is to locate the fault, if possible, by inspection. If this cannot be done, take the loop wire out of plate *L* and put it into post *2* on the reverse switch. The effect of the change is to use the part of the field *r* to run the car, the part of the field between *o* and the reverse switch not being used at all. In such a case, the shoe *S* must not be shoved around to plate *L*, because *L* is not connected to anything, and the effect of putting shoe *S* on it would be to open the circuit.

---

### OPEN CIRCUIT ON A SHUNTED FIELD.

**34.** Fig. 6 is a plan of the car wiring when the field has a shunt on it. An open circuit in the field coil itself or anywhere on wire *K–F–* makes the car helpless unless the fault

can be found and removed. As soon as the shoe touches plate $L$, the shunt gets a very big current, and will burn out unless the blowing of the main-motor fuse saves it. Of course, if the faulty field coil can be located, even if it cannot be fixed, it can be cut out, as has been shown. In such a case, the shunt or loop wires, for reasons already given, must also be cut out.

# CAR EQUIPMENT.

(PART 5.)

## OLD-RHEOSTAT SINGLE-MOTOR CONTROL.

### WRONG CONNECTIONS.

#### FUSE BOX.

**1.** As far as the fuse box is concerned, there is very little chance of making a connection that could be called wrong in the sense that it could do any harm, although it might be slightly irregular. It makes no difference at which end the current goes into or comes out of the fuse, the electrical effect is the same; but, if the box is wrongly connected, it makes a clumsy-looking job. Fig. 1 (*a*) shows the fuse box connected as it should be. Fig. 1 (*b*) shows it with the two sections of trunk wire interchanged, and the crossing of these wires gives the job a very unworkmanlike appearance. Fig. 1 (*c*) shows the fuse box connected in the only wrong manner possible. When so connected, the fuse is cut out of circuit and is of no use as a protector.

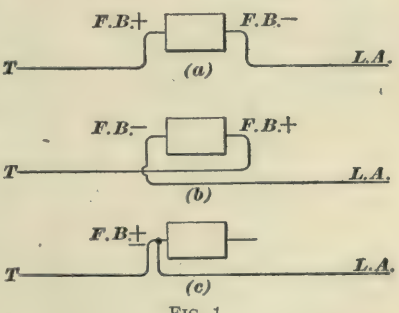


FIG. 1.



For notice of the copyright, see page immediately following the title page.

LIGHTNING ARRESTER.

**2.** The effects of making wrong connections on the several kinds of lightning arresters, having been discussed, they will not be repeated here.

---

RHEOSTAT.

**3. Rheostat Without Loop or Shunt.**—When the rheostat is used without either loop or shunt, there is no place where a wrong connection is apt to be made, because in Fig. 2 there are only two wires running to the rheostat—the $F+$ field wire and the trolley trunk wire—and, as the wire from the fuse box is just in line with the rheostat-arm post where it goes, a workman must go far out of his way to get it into the post where the $F+$ wire is intended to go.

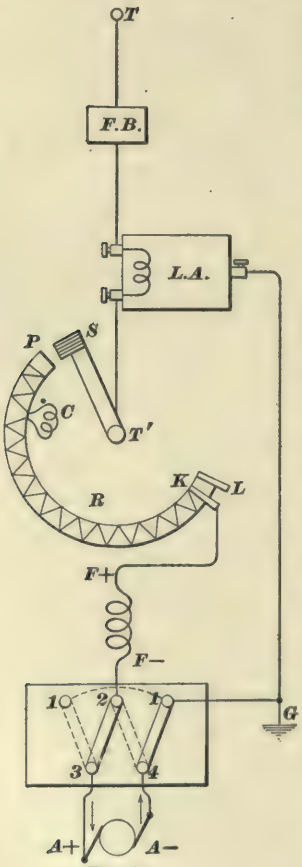


FIG. 2.

**4. Rheostat With Loop.**—If the motor has a loop wire, Fig. 3, it is very easy to get the $F+$ field wire running into $K$ and the loop wire running into $L$ confused, because they are very close together throughout their length. Such an error in connections is indicated by the dotted lines in Fig. 3. With the loop wire running into $K$, as shown here, the current passes through the loop wire as soon as the shoe $S$ touches plate $P$; since the $F+$ field wire runs to $L$, which does not act until the shoe touches it, the car starts up on that part of the field coil which lies between $F-$ and $L'$. The starting power

of the car is, therefore, very much reduced. As soon as the shoe touches plate $L$, no effect is noticed, because it simply places the unused part of the field in multiple with the loop wire, which short-circuits it. With the $L$ and $K$ wires interchanged, then that part of the field coil, which, with the proper connections, is only cut out when plate $L$ acts, is cut out all the time. Before $S$ touches $L$, the part $L'F+$ is cut out, because the $F+$ end goes to $L$, which hangs in the air without any connection; after $S$ touches $L$, this part of the field remains cut out because the loop wire is thrown right across it. The symptoms of such a state of things are that the car is slow in starting, and the throwing in of the loop makes no difference in the speed.

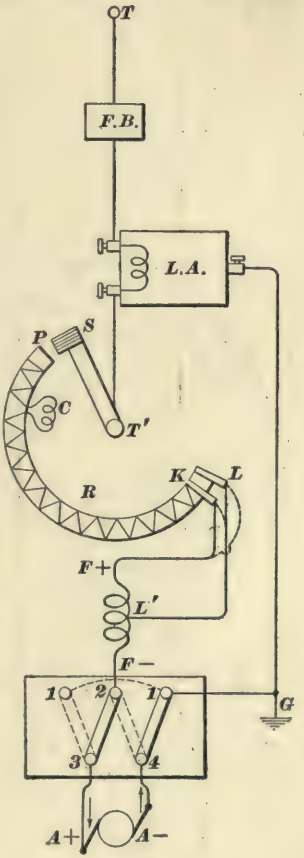


FIG. 3.

**5. Rheostat With Shunt.**—Where the shunt is used, Fig. 4, the same confusion is liable to take place, but with very different symptoms to indicate the fact. The dotted lines indicate the supposed error in the connections; the full lines show the connections as they ought to be. If the field wire runs into $L$, it might, as in the last case, just as well run out into the air somewhere, because $L$ is not connected to anything until $S$ touches it. On the other hand, with the shunt wire in plate $K$, the shunt gets all the current that the line can send through $R$ as soon as $S$ touches $P$; but the car cannot move, because there is no field for the armature to turn in, and the shunt gets very

hot. If shoe $S$ is moved around until it touches $K$, the current gets so large that the shunt cannot stand it, and very often becomes white hot, and perhaps burns out. If the shoe gets around as far as plate $L$, the field is thrown in multiple with the shunt, and the car starts, but this fact may not decrease the amount of current that the shunt gets promptly enough, and it is bound to burn up unless the fault is discovered in time and removed. If the true state of things is found out too late, and the shunt burns out, the car will take no current until $S$ touches $L$, when the car will start with a jerk. If the shunt lasts until the shoe reaches $L$, where the field is thrown in, it may be saved for the time being, because, as soon as the motor gets a field, the armature begins to generate its counter E. M. F., which checks the flow of the current; but if the car has much starting and stopping to do, this temporary relief on the final position does no good, because on all other "on-positions" the shunt is abused. To relieve the situation, the shunt may be disconnected altogether, and the $F+$ field wire put into $K$, where it belongs. The first symptom of a confusion of this kind is the odor arising from the heating of the shunt's insulation; this odor once experienced is never forgotten; it is entirely different from the odor that comes from a defective motor. The next strong symptom is in the fact that, although a large current flows, the car refuses to start until the shoe gets to the final

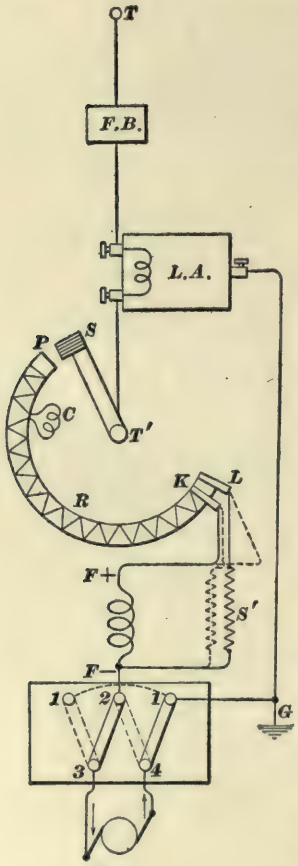



FIG. 4.

position. These two symptoms, together with the abnormal heating of the shunt, disclosed by feeling it, locate conclusively the seat of the trouble.

---

### FIELD.

**6. Wrong Outside Connections.**— The motor fields are liable to wrong connections of two kinds, *outside* and *inside*. The outside ones have to do with the $F+$ and $F-$ leads that connect to the rheostat, and reverse switch, respectively; the inside ones have to do with an error in connecting together the field coils themselves. In Fig. 5 (*a*) and (*b*), the letters have the same meaning as usual.

In (*a*), the top field lead goes to the rheostat, and the bottom lead to the reverse switch; the current then enters the field at the top lead and goes out at the bottom, and the car is assumed to go ahead when the reverse handle points ahead and the switch blades are in the position shown.

In (*b*), the leads are supposed to have been interchanged by mistake, the top lead going to the reverse switch and the bottom lead to the rheostat. In this case, the current enters the field at the bottom lead and reverses the polarity of the field coil. For reasons that have already been taken up, the direction of rotation of the armature is reversed, and hence the direction of motion of the car for the given position of the switch blades is also reversed. The car then goes ahead when the reverse handle points back. To right matters, it is only necessary to cross the field or armature leads as in Fig. 5 (*a*).

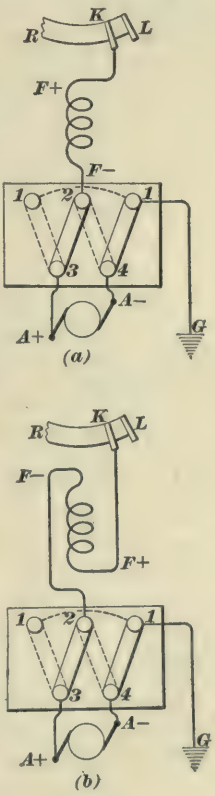



FIG. 5.

**7. Wrong Inside Connections.**—Fig. 6 (*a*), (*b*), and (*c*) show two field coils of the general shape used on up-to-date motors. There are four such coils in each motor, and all the coils are exactly alike. Each coil has an inside end, marked *I*, and an outside end, marked *O*. The inside ends can be told from the fact that there is always a bump on the coil where the inside end is brought to the surface. In the motor, an inside end should always connect to an inside end, and an outside end to an outside end, leaving two inside ends or two outside ends to be brought out of the motor for the *F*+ and *F*− leads. Fig. 6 (*b*) shows the proper connection for two fields; for example, suppose these two fields go into the top half of the motor; two others, connected in just the same way, go into the bottom half; the two terminals made up of one end of each pair are connected together and the two remaining ends are brought out of the motor to form the *F*+ and *F*− leads. There are two ways in which these coils can be improperly connected together. Fig. 6 (*a*) shows one way; here the right-hand coil has been given a half turn around. Fig. 6 (*c*) shows the second way; here the right-hand coil has been flopped over on its back like a turtle.

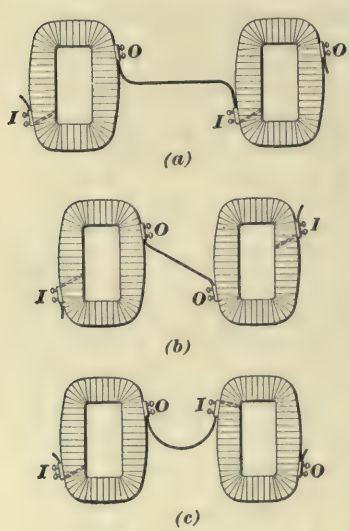


FIG. 6.

On account of one side of the coil being shaped to fit the inside curve of the motor frame, there is no excuse for putting in the coil this way, as it has to be forced, but, nevertheless, it is sometimes done. The result of both these errors is to bring two neighboring coils together in such a way that the inside of one is connected to the outside of the other. The effect of this is to have the current enter and leave the two coils in the same way, with the result that

both coils make their pole pieces either N or S; whereas one should be N, and the one next to it, on either side, should be S. If the current enters a coil at its inside end, it should enter the coil next to it at its outside end. The effect of one reversed coil on a single-motor car is to make the car start slowly, cause the brushes to spark, and perhaps blow the fuse when *S* touches *K*. If the two coils are reversed, the car will not start at all. In such a case, nothing can be done but to open the motor and find the trouble.

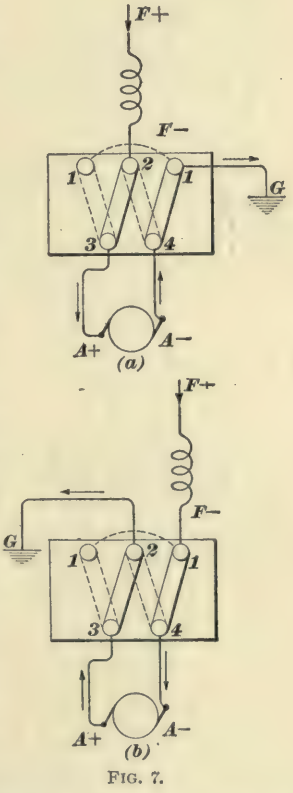


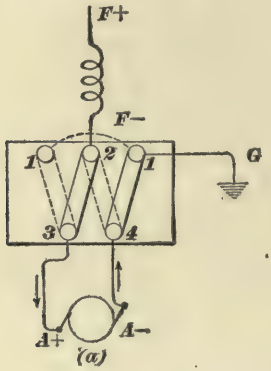
FIG. 7.

### REVERSE SWITCH.

**8.** The confusion of reverse-switch connections will be considered in connection with Fig. 2. First suppose the *F*— field wire and the ground wire to be interchanged; in Fig. 7 (*a*), the reverse-switch connections of Fig. 2 are reproduced; in Fig. 7 (*b*), the wrong connection is shown. In Fig. 7 (*a*), the current goes into the armature at the left-hand brush, and leaves at the right-hand brush; in Fig. 7 (*b*), for the same position of the reverse switch, the current goes in at the right-hand brush, and comes out at the left-hand brush. If the switch is on the dotted position, the current enters the armature the same as in Fig. 7 (*b*). The effect of interchanging *F*— and *G*, then, is to reverse the motion of the car, as in Art. **6**.

**9.** Suppose the ground wire and the *A*— armature wire going into post 4 become confused. Fig. 8 (*a*) shows

the proper connection and (*b*) shows the confused connections. As long as the reverse switch is in the position shown in the figure, the car starts and runs just as usual, because the path of current *F*+–*F*––*2*–*3*–*A*+–*A*––*1*–*4*–*G* is the same as in Fig. 8 (*a*); but if the switch is thrown to the dotted



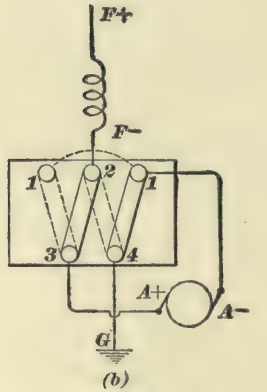
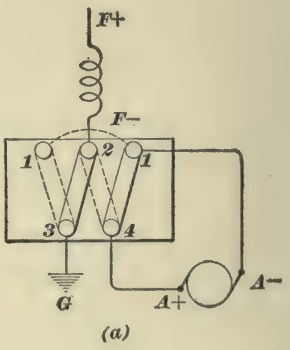




FIG. 8



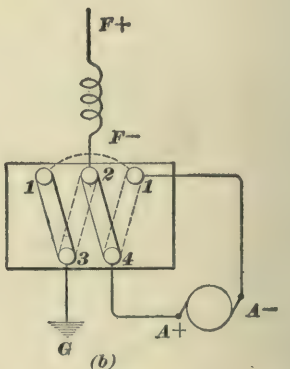




FIG. 9.

position, the path becomes *F*+–*F*––*2*–*4*–*G*, cutting out the armature and grounding the field. The symptom is the same as that for a grounded brush holder, except that the car can run ahead instead of back, as in the case of a grounded brush holder.

**10.** Next, suppose the ground wire and the *A*+ wire going into post *3* become confused. In Fig. 9, (*a*) shows

the wrong connection with the reverse switch at go-ahead, and (*b*) the same, but with the reverse switch at back-up. The effect is the same as in Art. **9**, except that the car will now back up, but cannot go ahead, because the current grounds through the path *F*+–*F*––*2*–*3*–*G*.

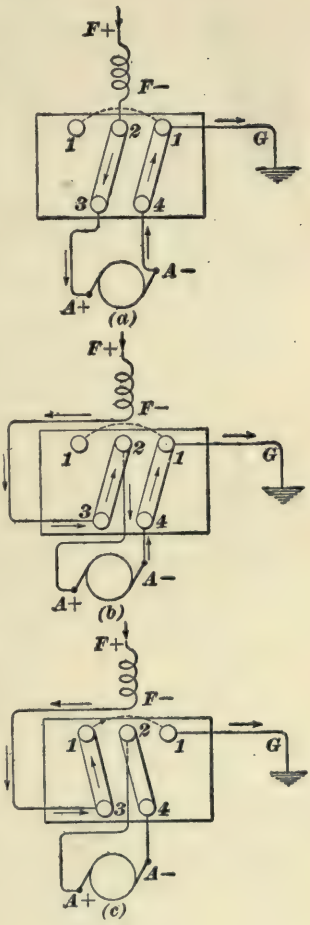


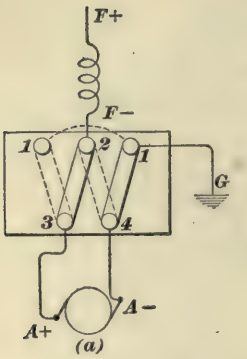
FIG. 10.

**11.** Next, suppose the *A*+ armature wire going into post *3* and the *F*– field wire going into post *2* become confused. In Fig. 10, (*a*) shows the right connection, and (*b*) shows the path of the current after the interchange is made and with the reverse switch at go-ahead. The car can go ahead all right, for the path of the current is *F*+ –*F*– –*3*–*2*–*A*+ –*A*– –*4*–*1*–*G*. Fig. 10 (*c*) shows that the car cannot be backed up, because, as soon as the reverse is thrown over, the path of the current becomes *F*+ –*F*– –*3*–*1*–*1*–*G*, the current going right to earth.

---

ARMATURE.

**12.** If the *A*+ and *A*– armature wires become confused, the effect is the same as when confusion occurs with the car wires going into posts *3* and *4*; that is, the car backs up when the reverse handle points ahead, and goes ahead when the reverse handle points to the rear. In Fig. 11, (*a*) and (*b*) give the right connection



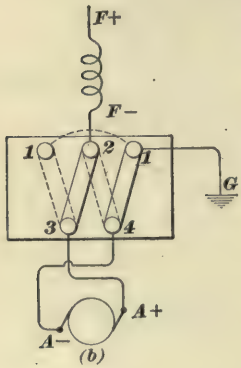




FIG. 11.

and the wrong connection, respectively. In (*a*), the current goes into the armature at the left-hand brush holder; in (*b*), at the right-hand brush holder.

## SINGLE-MOTOR DOUBLE-END CONTROL.

### GENERAL CONNECTIONS.

**13. One Rheostat.** — In a great many cases where a car has a single motor controlled from both ends, it is the custom to use a single rheostat and to mount this rheostat either on one end, as in the case of single-end control, or to mount it in the middle of the car and run cables to the controlling staffs on either end of the car. When the rheostat is mounted on the end, it is connected to the staff that it is nearest just as usual, and a wire cable is run

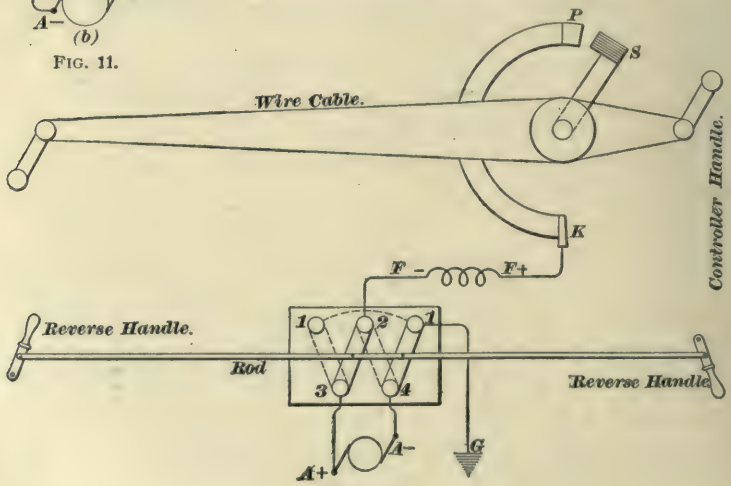



FIG. 12.

to the staff on the far end; the reverse switch must, of course, have a connecting-rod of its own. Fig. 12 gives an idea as to how it is done. As a matter of fact, the reverse handle and the controller handle turn around the same

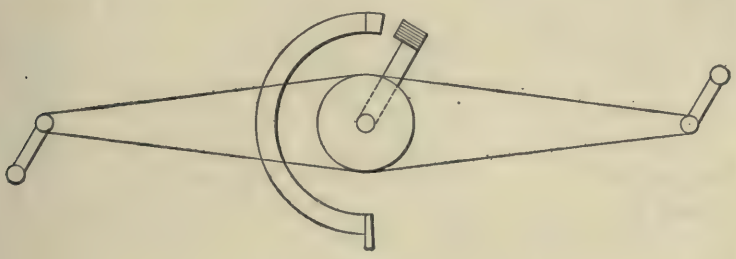


FIG. 13.

center, but so small a drawing would not show this as clearly as Fig. 12. Fig. 13 shows how the cable is run when the rheostat is hung under the middle of the car. As the reverse switch is operated on the same principle as that shown in Fig. 12, it is not reproduced in Fig. 13.

**14. Two Rheostats and One Motor.**—Fig. 14 gives the connections on a single-motor car, controlled from both ends and by means of two rheostats. Where there are two rheostats, a car is less apt to become helpless, because, if the front controller gives out, the rear one can be used. This diagram approaches more nearly an up-to-date car-wiring diagram than any that has been considered up to this point. Two wires *T'-T'-T'* and *K-K'* run the full length of the car. Of course, when one controller is in use, the other is not, and it is, therefore, at the off-position; if the right-hand controller is in use, the path of the current is *T-F.B.-L.A.-X-T'-T'-S-P-R-K-O-F+ -F- -2-3-A+ -A- -4-1-G*; if the left-hand controller is used, the path of the current is *T-F.B.-L.A.-X-T'-S'-P'-R'-K'-O-F+ -F- -2-3-A+ -A- -4-1-G*; the two rheostats are simply in multiple, as can be more clearly seen in Fig. 15, where they are placed alongside of each other, instead of at

opposite ends of the car; the connections in Figs. 14 and 15 are exactly the same, and all the letters have the same meaning.

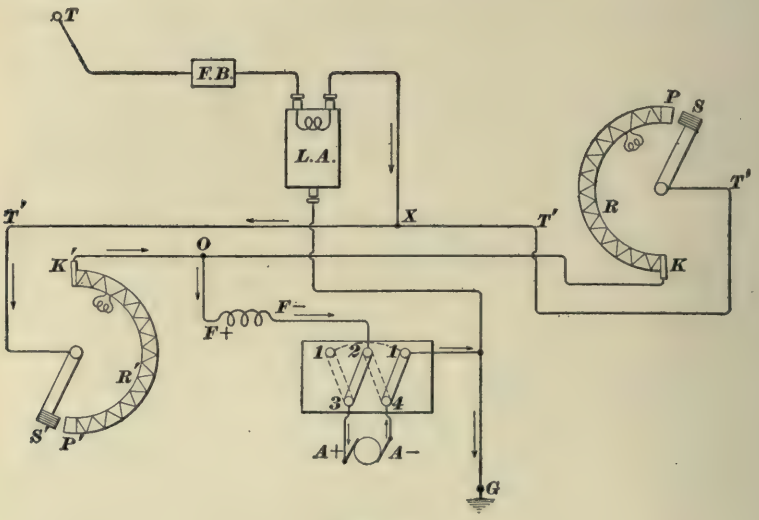



FIG. 14.

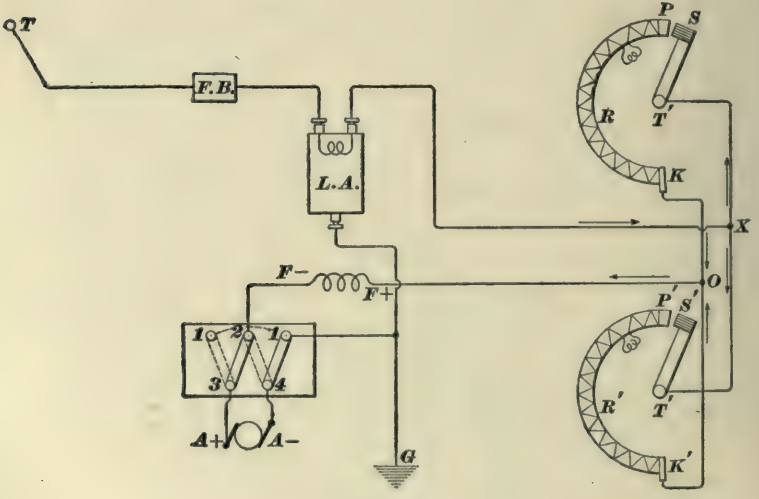



FIG. 15.

**15. Open Circuit.**—In Fig. 15, assuming both controllers to be on, the current from the fuse box splits as soon as it gets to point *X*; part of it goes through the upper rheostat and part of it through the lower one; the two parts run together again at point *O*, and take a common path through the motor and the reverse switch. Now, if any trouble occurs so that the car can be run from one controller, but not from the other, the symptom indicates that the trouble is in the local circuit of the rheostat from which the car will not run, and it must lay somewhere between points *X* and *O*, because everywhere else the circuit is common to both rheostats, and a fault on any common part of the circuit would make it impossible to run from either rheostat. When a car with two controllers, then, develops a fault that disables both of the controllers, the chances are that the fault is in the motor itself; if not there, in some portion of the trunk wiring outside of *O* and *X*, or in the reverse switch.

**16. Both Rheostats On.**—As soon as the pole is on and the hood switches are in, the motor circuit is closed everywhere except on the rheostat; since the two rheostats are in multiple, the closing of either will start the car. If, after the car is started and the shoe on the rheostat that is in use is moved around to the last position, it is possible to turn the rheostat on the rear end around to the last position without the motorman knowing anything about it until he tries to stop his car and finds that he cannot do so, because, although he may throw his own rheostat off, the current still finds its way through the motor circuit by way of the rear rheostat. Such a condition of affairs is not very liable to happen, but there are two cases on record due to two different causes. One case was due to the shoe *S* jolting around on to plate *P* and sticking there. The other was due to a small boy jumping up on the rear end and turning the staff with a wrench. In such a case, the best thing to do is to throw off the hood switch.

## OLD-RHEOSTAT MULTIPLE CONTROL.

### ONE RHEOSTAT AND TWO MOTORS, ONE REVERSE SWITCH AND NO CUT-OUT.

**17. Method of Wiring.**—Fig. 16 shows the car-wiring diagram for two motors controlled by one rheostat and one reverse switch; there is neither loop, shunt, nor cut-out. $F_1+$ and $F_1-$ are the two field leads of the No. 1 motor; $F_2+$ and $F_2-$ are the two field leads of the No. 2 motor; $A_1+$ and $A_1-$ are the armature leads to No. 1 motor; $A_2+$ and $A_2-$ are the armature leads to the No. 2 motor. On a single-end car, the rheostat is on the front end, and the No. 1 motor is the motor nearest to the rheostat; the No. 2 motor is the rear one. On a double-end car, the fuse box is generally considered to mark the front end, so the No. 1 motor is the one nearest to the fuse box. In Fig. 16, the path of the current from $T$ to $G$ is as follows: $T$–$F.B.$–$L.A.$–$T'$–$S$–$P$–$C$–$R$–$K$–$\left\{\begin{matrix} F_1+\text{–}F_1- \\ F_2+\text{–}F_2- \end{matrix}\right\}$–2–3–$\left\{\begin{matrix} A_1+\text{–}A_1- \\ A_2-\text{–}A_2+ \end{matrix}\right\}$–4–1–$G$. The meaning of the first bracket is that when the current gets to point $x$, it splits, one half of it going through the field $F_1+$–$F_1-$ and the other half going through the field $F_2+$–$F_2-$. The meaning of the second bracket is that the current again splits at post No. 3, one half going through No. 1 armature $A_1+$–$A_1-$ and the other half going through No. 2 armature $A_2-$–$A_2+$.

**18.** It must be noticed right here that the left-hand brush on No. 1 armature is marked $A_1+$, and the right-hand brush $A_1-$; but on No. 2 armature, the left-hand brush is marked $A_2-$, and the right-hand one $A_2+$. This is done to indicate the fact that one set of armature leads must be reversed so that the two motors will run the car in the same direction. This crossing of the leads must be done because the motors are mounted back to back on the truck. Assuming

that two motors are wound and connected alike and that the leads are brought out of the motor frame alike; then, if the two motors were set on the floor with their pinions turned the same way, in order to have the armatures turn in the same direction, it would be necessary to connect the motors alike. That is, if the current went into the top field of one, it should go into the top field of the other; and if it went into the left-hand brush of one, it should go in at the left-hand brush of the other; and two motors so set and so connected would concur in running any machine to which their pinions might be geared. Now, if one motor be turned end for end, so that its pinion points in the same direction as the commutator of its mate, it will be necessary, in order that the two pinions may tend to urge a gear in the same direction, to have the rotation of one of the pinions reversed. Fig. 17 may help to show clearly why this is so. In Fig. 17, friction pulleys have been taken instead of pinions, because they make an easier diagram to draw. The two motor armatures are provided with friction pulleys $A$ and $B$, and the motors are set up so that the two pulleys point towards the reader, as indicated by the dots at their centers, and so that they bear against the large pulley $C$, which they are to turn. Since the two motors are alike in every respect, and since

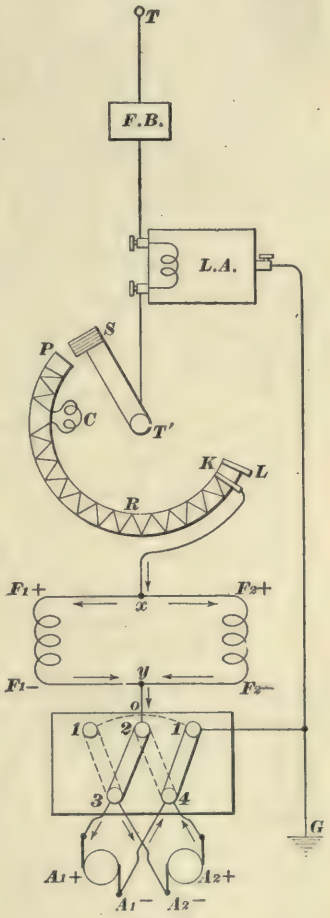


FIG. 16.

they are connected in the same way, as cited above, they will, when supplied with current, turn their armatures in the same direction; let this direction be that of the hands of a clock, as shown by the arrows. As soon as *A* and *B* begin to turn in this direction, the large wheel, urged by both of them, turns in the opposite direction. Now, in Fig. 17 (*b*), suppose the motor having pulley *B* to be turned around end for end, as indicated by the cross in the center of its pulley. Since its connections have not been changed, its pulley keeps on turning in the same direction; but, since the motor has been turned end for end, it now presents the opposite side of its pulley to the large pulley *C*; thus, on any pulley or pinion in motion, one side travels up and the other side down. In Fig. 17 (*a*), the up-turning side of *B* was next to *C*, and urged *C* around in the same direction as *A*. In Fig. 17 (*b*), the down-turning side of *B* is next to *C*, and urges it in the same direction as the hands of a watch. Now, since *A* urges *C* in the same direction as it did before, and *B* urges it in the opposite direction, *B* and *A* are opposed, and, as a result, if all three were pinions so that there could be no slippage, *C* could not turn at all. To make matters right, it is only necessary to reverse the field or armature leads on *B*'s motor. Hence the necessity of reversing the armature leads on the No. 2 motor, as shown in Fig. 16. The crossing of the field leads would do as well.

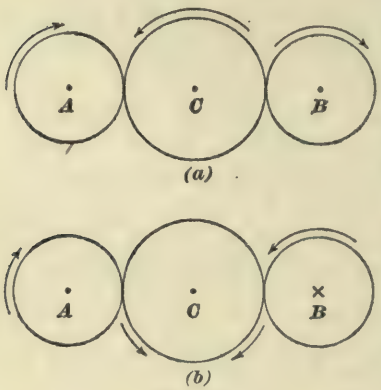


FIG. 17.

**19. Troubles.**—In Fig. 16, it will be noticed that the fields and armatures of the two motors are so connected that if a fault occurs on one motor, the motorman will have to lift the traps in the car and disconnect the motor entirely

before he can get rid of the fault. Suppose, for instance, that a ground or open circuit occurs in the No. 1 field coil. The motorman's most natural move would be to disconnect the No. 1 motor's field at both ends (at $F_1+$ and $F_1-$) without disconnecting the No. 1 motor's armature. Such a step would result in a dead short circuit through the field of No. 2 motor and the armature of No. 1 motor; because, since No. 1 motor has no field, its armature can generate no counter E. M. F., and current from the rheostat rushes through it by way of path $K$–$F_2+$–$F_2-$–2–3–$A_1+$–$A_1-$–4–1–$G$ to the rail. The lesson to draw from this is, that whenever occasion requires that one of the motor fields be cut out on a car equipped in this manner, the armature should be cut out as well. To cut out the field, its leads must be disconnected, but drawing out the brushes will cut out an armature.

**20. Field and Armature Leads.**—The effect produced by a ground on the field will depend on where the ground is; if the ground is on the $F_1+$–$F_2+$ wire, or on the wire connecting this wire to the rheostat at $K$, the car cannot start if the ground shows up while it is standing still, and if the fault occurs while the car is in motion, the main motor fuse will blow, because all the resistance is cut out of the rheostat. If the ground occurs inside of the field coil on either motor, the car will buck, if in motion, just as on a single-motor car, because part of the motor field becomes separately excited and both armature leads become grounded, one through the fault, and one through the ground wire. The nearer the ground occurs to the $F_1-$–$F_2-$ wire, the more severe will be the bucking, because the number of turns that become separately excited will be greater. If the ground takes place on the $F_1-$–$F_2-$ wire or on the wire that connects this wire to the No. 2 post on the reverse switch, it is easy to see that the large ground current flows through both motor fields, separately excites both of them, and therefore enables both armatures to buck. If a ground shows up on this wire, it must be removed before the car can be moved, because this wire is common to both motors, and cutting out

one of the motors does not remove the faulty wire. The same symptom takes place if either of the plus brush holders or brush leads become grounded, except that in this case, as in the case of the single motor, the car can be started backwards if the reverse switch be thrown to the dotted position. Care should be taken, as stated above, to be sure and disconnect the armature belonging to the field that has the fault. If an open circuit occurs in any wire leading to either armature (this includes all open circuits caused by the breaking or loss of brushes), the field belonging to that armature must, unless the open circuit can be found and removed, be disconnected, because, as the two motor fields are permanently connected at both ends, they are in multiple with each other, and one is, therefore, a shunt on the other. As long as both armatures are working, this is all right, but as soon as one armature circuit opens, the field on the idle machine becomes a permanent shunt on the one that is working, and weakens it so much that the good motor takes an overload, if, indeed, it does not buck as soon as the shoe touches *K*; for it must be borne in mind that the fields are of about the same resistance and this resistance is too low to be used as a shunt. A shunt should measure at least twice as much as a field, hence, it is not out of place here to state the fact that since the fields on different types of motors have different resistances, a shunt that is all right for one motor may be all wrong for another; in one case, it might be so low as to overload the motor, and, in another case, it might be so high as to fall very far short of its purpose.

**21. Grounded Armature.**—A grounded armature will, as a rule, run with a jerky motion if it will run at all, and, even if it is able to contribute nothing to the running of the car, the jerky motion will show itself when the car is run on the good motor.

**22. Open-Circuited Armature.** — An open-circuited armature will run with a ball of fire around the commutator, and the symptom is apt to be more pronounced on a two-

motor car, because the good motor keeps the car going. Of course, the best thing to do when a fault shows up on one of the motors of a two-motor car, is to cut out the bad motor and run home on the good one. The greatest care must be taken that, when one part of the motor is cut out, the other part should be cut out also, or great injury may be done to the remaining member.

**23. General Remarks.**—Of course, a ground cannot take place on any system of wiring without its effect being noticed. If it takes place while the car is in motion, the fuse is apt to blow or the motor to buck; if it takes place while the car stands still, there either will be a noticeable difference in the way the car starts, or it will refuse to start at all. An open circuit in the wiring is different; it may occur at any time, and give no other symptom than an effect on the speed of the car. An old motorman will soon notice this, but a new one may not until a field or amature revolts against abuse, and begins to smell and smoke. An open circuit on any wire common to both motors, such as wires $K$–$x$, and $y$–$2$, will disable the car, but an open circuit may exist on a field or on an armature lead for some time before it is found out, because, though the motor on which the fault lies can do no work, its mate goes on working until it is disabled as a result of the abuse it gets. There is no end to the list of troubles that street-car men had to contend with on equipments of this kind, but it was only these very troubles that urged the changes to be found in the apparatus that goes to make up an up-to-date equipment as we now know it.

**24. Equipment With Loop or Shunt.**—Figs. 18 and 19 are along the same lines as Fig. 16, except that Fig. 18 shows a loop connection, and Fig. 19, a shunt. What has been said in connection with Fig. 16 is true of Figs. 18 and 19, and the troubles to which the shunt and loop and their wires are liable add several new and interesting features to the list. A ground on the shunt or loop, or on the shunt or loop wire, amounts to nearly the same thing as a ground on the wire

$F_1$—$F_2$— connecting the negative field leads to the No. *2* post on the reverse switch. The bucking action is more severe in the case of a grounded shunt wire, Fig. 19, than in the case of a grounded loop wire, Fig. 18, because when the

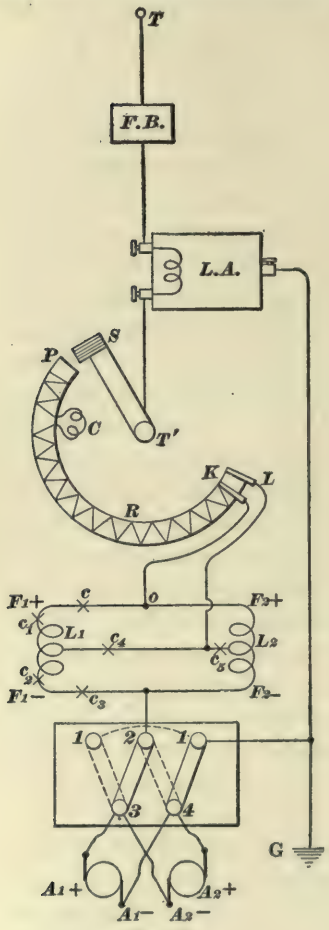



FIG. 18.

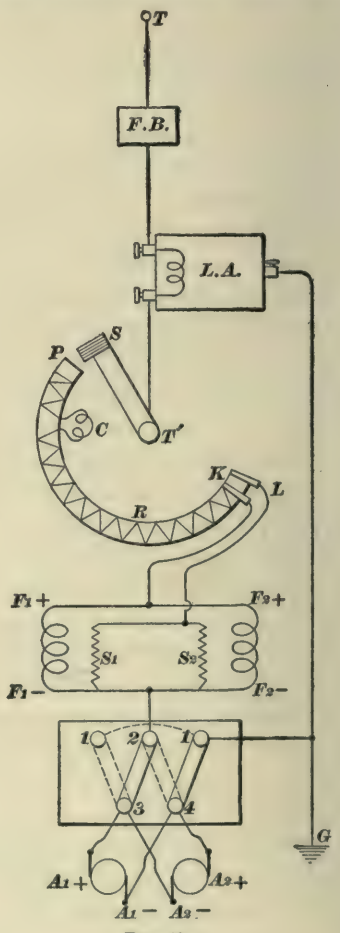



FIG. 19.

shunt wire grounds, the whole of both motor fields becomes separately excited, but when the loop wire grounds, only a part of the field coils is separately excited. The effect of a grounded loop or shunt wire is felt as soon as shoe *S* touches

plate *P*, because, although the plate *L* brings the shunt or loop into action, and is not touched by *S* except on the last position, it must be borne in mind that one end of the shunt or loop wire is permanently attached to the field coil, and a ground on either of these wires amounts to the same thing as a ground on the field coil itself. The following questions might suggest themselves to the student:

1. If one motor has a grounded field and must be cut out of the circuit, is it necessary to disconnect its shunt also?

2. If the two motor fields are in multiple, why cannot one large shunt be used across both fields instead of a small shunt across each field?

In answer to the first question, it may be said that it is best to disconnect the shunt when cutting out a motor; for, whether the No. 1 shunt will communicate the ground to the No. 2 motor or not, depends on how the shunt is tapped on to the field wire. Fig. 20 (*a*) and (*b*) may help to throw some light on the matter. In Fig. 20 (*a*), one end of each shunt is tapped on to the motor lead itself, so that when the lead is pulled out of the two-way connector at *c*, the shunt remains tapped on to the faulty field. Since the other end of the shunt is tapped on to wire *o o*, which connects to No. 2 shunt, and since one end of No. 2 shunt is permanently attached to No. 2 field, the effect of the ground on No. 1 field is transmitted to No. 2 field, and No. 2 motor cannot be used until No. 1 shunt is disconnected; this can be done by pulling one end of No. 1 shunt out of its connector. Fig. 20 (*b*) shows the two permanent shunt taps to be made outside of the field-lead connector, so that when the field lead is pulled out of the connector, the grounded field is cut off from the shunt entirely and cannot have any effect on the No. 2 motor. But the very bad feature remains that both shunts are now thrown in multiple across the field of the No. 2 motor, and this shunting power is more than the single motor can stand without a great deal of sparking at its brushes, and a great deal of heating in its armature whenever the rheostat is run on its final position.

Fig. 20 (*c*) is the same as (*b*), but the latter is clearer,

and, in answer to the second question, shows more plainly why a single low-resistance shunt cannot be safely used instead of the two higher resistance ones. The reason is, that in case one motor is cut out on account of a grounded field or armature, the shunt would have to be cut out too, because, if left in, it would, by its great shunting power due to low resistance, injure the good motor. On the other hand, depriving the good motor of its shunt, not only lowers the speed of the car, but makes the field coils become a great deal hotter, which is a bad feature. It is best, then, to have a shunt coil for each motor, and, in case of having to cut out a motor, its shunt coil should be cut out also. Where there is any doubt as to whether the shunt is cut out or not, or where the jumping of the car on the last notch proves that the shunt is not cut out, the rheostat shoe should not be pushed around to the last position.

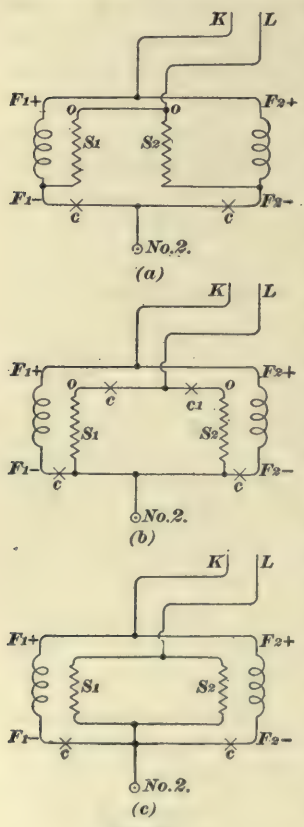


FIG. 20.

**25. Trouble in Loop.**—From Fig. 18, it is easy to see that the loop wire is a direct connection between the two motor fields, and that in case it is necessary to cut out a grounded motor, the loop wire would have to be cut out along with it, lest it transmit the ground to the good motor. Next, suppose an open circuit to occur in the No. 1 motor field, between $F_1+$ and $L_1$; that is, in that part of the field which is cut out when the loop wire is thrown into action by shoe $S$ touching plate $L$; such an open circuit is not soon detected, and it has a very peculiar effect. With an open

circuit, say at $c$ or $c_1$, Fig. 18, the upper part of the motor field can get no current; until the loop wire goes into action, the lower part, being in multiple with the lower part of No. 2 motor field, gets half of its current, so that up to the time that shoe $S$ touches plate $L$, both motors are working, but No. 2 armature has a stronger field than No. 1, because the whole current passes through the upper half of the No. 2 field, and half of the current passes through the lower half; whereas, on No. 1 motor, only one-half of the current goes through one-half of the field. In other words, No. 2 motor has three times as strong a field as No. 1 motor, with the result that No. 1 motor gets a great deal more than its share of the load, because, since its field is weak, its armature has a low counter E. M. F., and lets in a large current.

The effect of overloading one motor in this way is to skid the car wheels to which its armature is geared. As soon as the shoe $S$ touches $L$, the upper half of the field on No. 2 motor is cut out, both motors work on the lower half of their field coils, and, normal conditions being established, the load divides between the two motors as it ought to. Now, suppose an open circuit to occur at $c_2$ or $c_3$ in the lower half of the No. 1 motor field, this being the part that the loop wire does not cut out. As soon as the shoe is put on plate $P$, current passes through the rheostat to point $o$, when it divides, part taking the path $o$–$F_2$+–$L_2$–$F_2$– to the reverse switch, the other part taking the path $o$–$c$–$c_1$–$L_1$–$L_2$–$F_2$– to the reverse switch. All the current goes through the lower half of the No. 2 motor field, but, since the upper halves of the two motor fields are in multiple, each half gets but one-half of the current. Up to the time, then, that the loop wire is thrown into action, No. 2 motor has three times as strong a field as No. 1 motor, so that No. 1 motor takes an overload.

As soon as the rheostat is "put on the loop," there is a short circuit through No. 1's armature, and the main motor fuse blows. The reason of the short circuit is this: Up to the time that the loop wire is thrown in, the lower half of the No. 1 motor field can get no current on account of the open circuit at $c_2$ or $c_3$, and it is therefore dead. The only

field that No. 1 motor has, then, is due to one-half of the current flowing through the upper half of its field; No. 1 motor is already overloaded. As soon as the loop wire goes into action, it cuts out this upper half of the field coil and No. 1 motor has no field at all. The No. 1 armature then has no counter E. M. F., but is still in the circuit in multiple with the No. 2 armature, and an enormous current rushes through the idle armature to the ground, by way of path $S$–$P$–$L$–$L_2$–$F_2$–$-2$–$3$–$A_1+$–$A_1-$–$4$–$1$–$G$, which includes half of No. 2 field. An open circuit at $c$ or $c_1$, Fig. 20 (*b*), or at $c_4$ or $c_5$, Fig. 18, all of which are in the individual loop or shunt wire, will put one loop or shunt out of action, so that one motor will be running with a shunt, or loop, and one motor without any at all. The effect of such a fault is to overload the motor that runs with the loop or the shunt whenever the rheostat is on the final position, because the looped or shunted motor has a weaker field than its mate, so that the counter E. M. F. of its armature is lower, and lets in a larger current. The effect of an open circuit on the loop wire or shunt wire is to put both loops or shunts out of action. In such a case, the fields become much hotter, and the car speed fails to respond on the final position of the rheostat.

---

### EQUIPMENT WITH DOUBLE REVERSE SWITCH.

**26. Method of Wiring.** — Fig. 21 shows the wiring plan on a car equipped with one rheostat, two motors, and two reverse switches. This plan of wiring is much better in many ways than that of Figs. 16, 18, and 19, and comes very near the plan used on up-to-date systems of control, except in the methods of carrying out details. In the first place, one motor circuit is almost entirely independent of the other, and there is much less danger of a grounded motor being so cut out that the fault may lead back to the good motor on some cross-wire and make it unfit to run the car. From $T$ to $x$, the circuit is common to both motors, but from $x$ to $G$, there is a circuit for each motor. The path through the No. 1 motor is $x$–$F_1+$–$F_1-$–$2$–$3$–$A+$–

$A_1$—–4–1–1′–1′–$G$. The path through the No. 2 motor is $x$–$F_2$+–$F_2$—–2′–3′–$A_2$—–$A_2$+–4′–1′–$G$. There is no loop nor shunt shown in Fig. 21, and the plan is as simple as it can be made. Fig. 22 is given in order that the field and reverse-switch connections may be seen at a glance. Fig. 23 is the plan of the single reverse - switch connections.

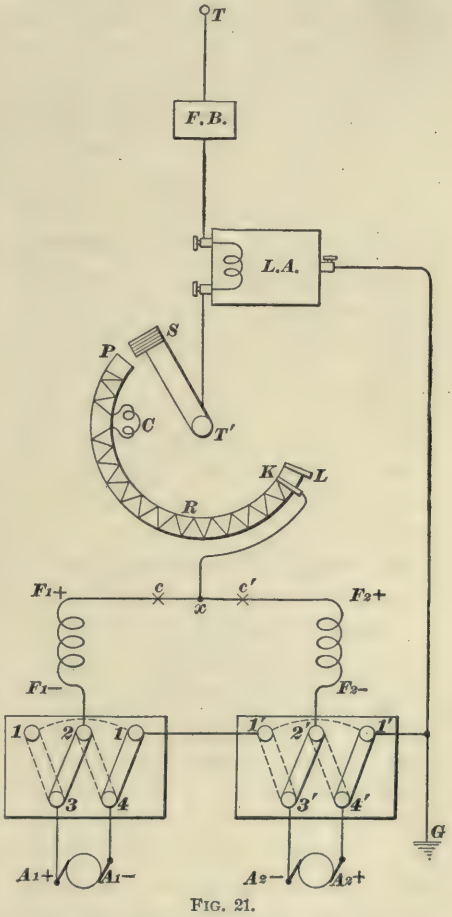


FIG. 21.

**27. Troubles.**— In case of a ground on either motor field or field car wire, the motor can be entirely cut out by disconnecting the field at $c$ or $c'$, depending on whether the fault is on the No. 1 or the No. 2 motor. This cannot be said of the plan shown in Fig. 23 (the single reverse switch), because even if the field is cut loose on the $F_1$+ end, the cross-wire $F_1$—–$F_2$— carries the ground over to the No. 2 motor field, and disables the No. 2 motor. This fact does away with the necessity of drawing the brushes on the armature of a motor whose field has to be cut out, and also of disconnecting the field of a motor whose armature has to be cut out. This suggests the idea, which is a

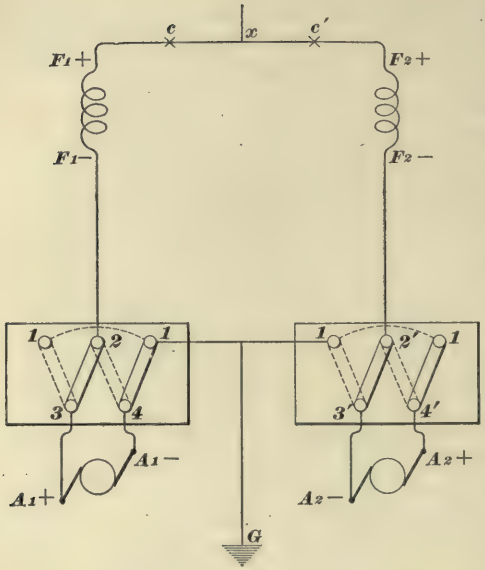



FIG. 22.

good one, that a very simple and quick way of cutting out a grounded motor could be provided by putting a switch at $c$ and $c'$. This has already been done. Of course, grounds on the motor produce the same symptoms as those explained in connection with Fig. 2, the wiring plan for a single motor, because Fig. 21 is no more nor less than the wiring plan for two single motors connected in multiple. There might be a difference in the degree to which the effect of the bucking could be felt, because, whatever might happen to one motor, the good motor tries to run the car until the main motor fuse blows. In case an open circuit shows up on one motor while the car is in motion, the motor is cut out because it can get no current, and the only effect felt is a check in the speed of the car. If the open circuit occurs while the car is standing still, the fact is indicated not only by the car starting slowly, but by the wheels slipping on curves, and in starting a load on a steep grade.

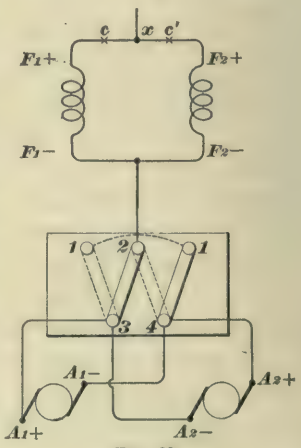



FIG. 23.

### USING THE MOTORS AS A BRAKE.

**28.** Any old motorman who has run a car equipment consisting of two motors and two reverse switches, knows that if the reverse handle is pulled back while the car is under headway, the car will not run far before its speed receives a very sudden and strong check, even if the controller handle is at the off-position, with both hood switches out, the pole off, and no power on the line. This shows that the cause of the sudden check to the speed is to be found somewhere within the equipment itself. This manner of stopping a car is known among motormen as *making the motors generate*, and this is actually what is done; but, before the details of what takes place can be clearly seen, one or more points must be considered in regard to dynamos, for a motor is a dynamo when it begins to generate.

**29. Picking-Up of Dynamo.**—In Fig. 24, $F+-$, $F-$ is the field and $A+-A-$ is the armature of a street-car motor forming a part of the closed circuit $T-A+-A--F+-F--K-R-P-S'$; $N$ is a pulley on the pinion end of the armature, and this pulley is belted to pulley $E$, which is driven by an

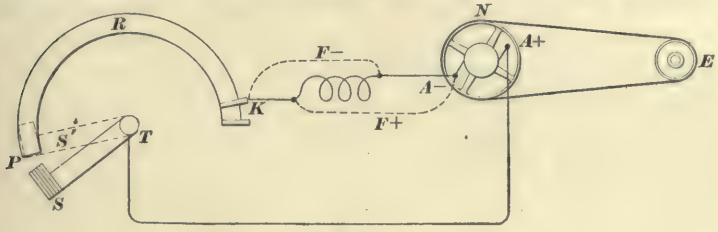



FIG. 24.

engine not shown. As soon as the engine begins to turn over, so does the armature; as soon as the armature turns, its wires cut the lines of force, due to a small amount of magnetism that the pole pieces have held over from the last charge that they received when the machine was running as a motor, and generate a low voltage. This low voltage sends a small current through the circuit, and, therefore, through the field coils, and this current increases the lines

of force that the armature has to cut, and again raises its voltage. This seesaw action between the magnetism and the voltage goes on until the voltage reaches a limit fixed by the design of the motor, the speed of the engine, and the current flowing. If the shoe *S*, of the rheostat *R*, were put on *K*, and the engine started up, the dynamo would pick up its field so suddenly as to throw the belt, because, the resistance of the circuit being very low, the current would be very large. If, however, the engine is started up first and the shoe put on plate *P*, then slowly pushed around towards *K*, there will be a point in its travel where the field begins to build up. It will run up to its full value rapidly, but the value of the current will be limited by the resistance in the rheostat. If the armature be driven by a motor instead of by a steam engine, the motor speed drops very much as soon as the dynamo picks up its field, because a load is thereby thrown on the motor. The point to be noted in particular is that the machine's ability to generate depends, in the first place, on the residual magnetism in its pole pieces.

**30. Conditions Required for Generation of E. M. F.** In order to have a street-car motor generate, the connections of its field and armature must have a certain relation to the direction in which the armature turns. A street-car motor is what is called a *series motor*. Series motors and series dynamos turn in opposite directions for any given way of connecting the fields and armature together; that is to say, if a motor runs in a certain direction, in order for it to act as a dynamo, with the same connections, it must be made to turn in the opposite direction; or, if it must run in the same direction as a dynamo that it ran as a motor, either its armature leads or its field leads must be reversed, as indicated by the dotted lines in Fig. 24. The reason of this will be taken up later.

**31. Relation Between Speed and Resistance.**—One peculiarity of dynamos is that they will not pick up a field until the armature speed reaches a certain value. In the case of series dynamos, the speed value depends on how

much resistance there is in the circuit; if the resistance is infinite, i. e., if the circuit is open, the dynamo cannot, of course, pick up its field at all, because the open circuit keeps any current from flowing around the field coils. If the resistance is practically zero, i. e., if the machine is short-circuited, as shown in Fig. 25, the dynamo picks up readily, because the seesaw action between the magnetism and the voltage can take place freely. The current value is limited only by the design of the machine up to a certain limit.

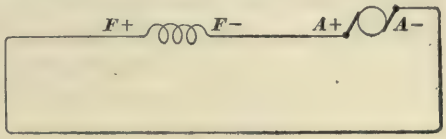


FIG. 25.

**32. Two Dynamos in Opposition.**—Two dynamos are said to be in opposition, when they are in series, as far as connections go, but have their polarities opposed; i.e., when one dynamo is trying to send the current in one direction, and the other dynamo is trying to send it in the opposite direction. In Fig. 26, $A_1+ - A_1-$ are the armature leads of one machine, and $F_1+ - F_1-$ are its field leads; $A_2+ - A_2-$ are the armature leads of the other machine,

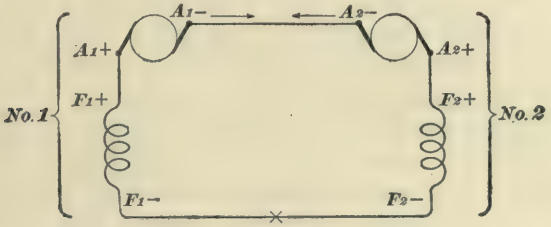


FIG. 26.

and $F_2+ - F_2-$ are its field leads. The connections are such that *No. 1* machine is trying to send the current around the circuit in the direction of the hands of a watch, while *No. 2* machine tries to send it around the other direction. If the conditions are such that the two machines have the same E. M. F., no current at all will flow, because one E. M. F. is balanced by the equal and opposite one. If,

however, for any reason the field on one machine becomes stronger than that on the other, the stronger field machine will force a current back through the weaker one and run it as a motor. If the two machines have no field, save that due to their residual magnetism, the machine that has the stronger residual magnetism will act as a dynamo and run the other as a motor. If both machines are run from an engine, the one that is run as a motor is apt to lose its belt. If both machines are under a car, one set of wheels will be seen to turn backwards.

**33. Braking Action of Motors.**—We are now in possession of the main feature involved in using the motors to brake a car, and are therefore in a position to follow an explanation of what takes place in such a case. In connection with Fig. 22, suppose the car to be moving at a fair rate of speed, and that the shoe of the rheostat be thrown to the off-position, the blades of the two reverse switches being thrown to the dotted position. As soon as the shoe is thrown off, all power is cut off so the car can receive no current from the line. The effect of throwing the two reverse switches is to cross the armature leads of both motors, thereby giving to them the connection of a dynamo for the given direction of motion of the car. The motor fields, the armatures, the two reverse switches, and the ground wire form a closed circuit $x$–$c'$–$F_2+$–$F_2-$–$2'$–$4'$–$A_2+$–$A_2-$–$3'$–$1$–$1$–$1$–$3$–$A_1+$–$A_1-$–$4$–$2$–$F_1-$–$F_1+$–$c$–$x$, in which both machines are connected as dynamos, and can generate a voltage because the pole pieces have a good residual magnetism. Each machine tries to be a generator and run its mate as a motor, and the machine that has the most residual magnetism can generate the most voltage, and therefore runs a current back through its mate and turns its armature as a motor. Now, as the throwing of the reverse switch has connected up both machines to run as dynamos for the given direction of motion of the car, as soon as one machine becomes motored, its armature and wheels begin to turn around in the opposite direction to what the motion of the

car calls for. If the car is under a good headway when the motors are reversed, as soon as one of them takes hold as a dynamo, the speed of the car gets a sudden and violent check, for the following reason: In the local circuit that includes the two opposing dynamos, there is no resistance save that of the motors themselves, and the machine that becomes a generator acts through a short circuit and can generate a large current. This gives the momentum of the car a lot of work to do, and, consequently, checks the speed.

**34. General Remarks on Braking Action.**—It is a good thing to know how to use the motors as brakes, for there is no telling when a brake chain may give away at the same time that the power is off, so that the reverse switch is of no use. It is not well, however, to make a practice of stopping a car in this way, for, since the fuse box is outside of the local circuit in which the dynamo acts, the machines are not protected in any way from an overload. Again, the sudden reversing of one armature strains the gear and pinion just as reversing or "plugging" a car under headway does. There have been several plans devised for using the generative ability of the motors to stop the car smoothly. They all depend on the use of a resistance to keep the current down to a safe value. Some work and some do not.

By looking at Fig. 23, it can be easily seen that where a car is wired with but one reverse switch, the motors cannot be made to generate, because there is no complete circuit through the field and armature of either motor; the armatures and fields are short-circuited on each other.

---

### DOUBLE REVERSE SWITCH WITH SHUNT AND LOOP.

**35. Diagram of Wiring.**—Fig. 27 shows the connections of the shunt, and Fig. 28 those of the loop used in conjunction with two reverse switches. In the case of the shunt, the brake action of the motors is apt to be less marked, because the shunt-car wire and the two shunts in

series are in multiple with the two fields, which are in series in the local circuit, so that the strength of the field coils is very much weakened. In the case of the loop, the same effect

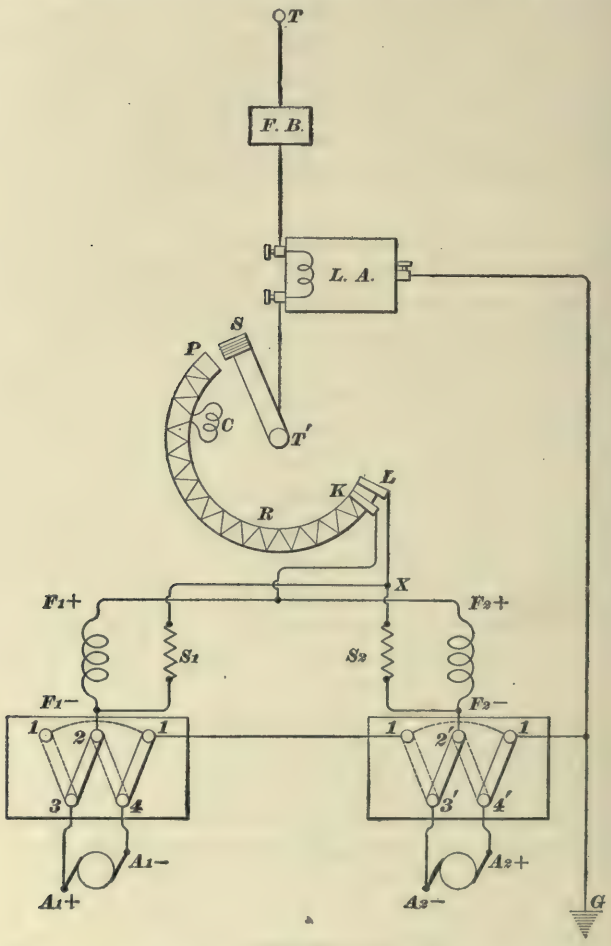



FIG. 27.

obtains, because the loop wire $L_1$-$L_2$ short-circuits the upper part of the field coils, leaving the lower part alone in action.

**36. Open Circuits.**—If, on account of an open circuit, the car cannot be made to move at all, it goes to prove that

the fault is not in either motor but is somewhere in between $T$ and $X$ or in the ground wire. The effect of an open circuit in either motor depends on where the break is. If, in

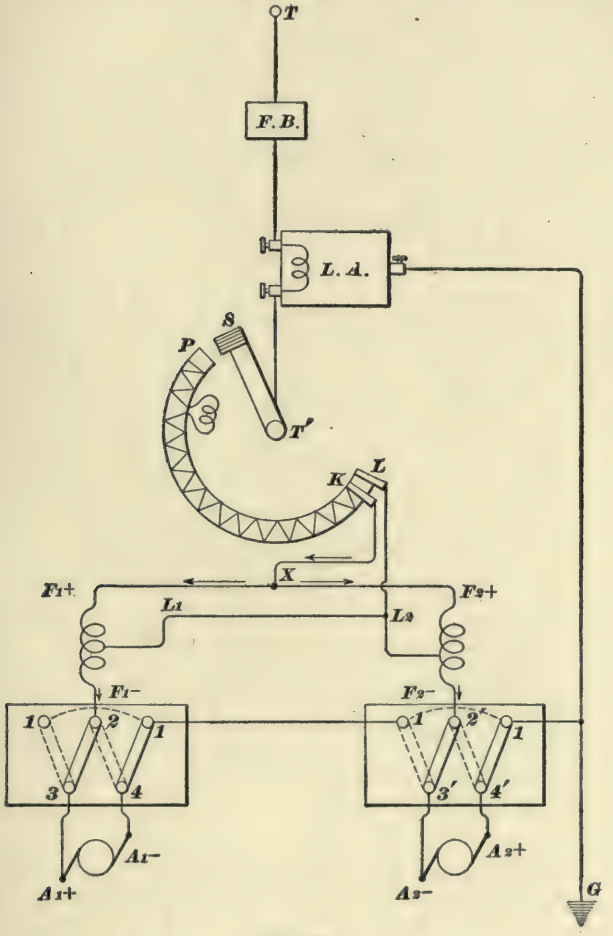



FIG. 28.

Fig. 27, an open circuit takes place in No. 1 motor field coil, the motor can get no field, and there is, therefore, a short circuit through No. 1 shunt and No. 1 armature as soon as shoe $S$ touches $L$. If the fault takes place in No. 2 motor,

so does the short circuit. A partial short circuit takes place, however, through the two shunts and shunt wire, as soon as shoe *S* touches plate *K*. In such a case, the rheostat should not be pushed around to the final position. An open circuit in either armature lead, due perhaps to a broken brush or a loose connection, can do no further harm than to cut out the motor on which it occurs. Such a state of things is indicated by the slow starting and slow running of the car, because one motor can neither start nor run a car as fast as two. An open circuit in the shunt wire anywhere on or between points *L* and *X* cuts out both shunts and pulls down the maximum speed of the car.

An open circuit in either shunt throws the remaining shunt across both fields, and its effect on the speed can be little felt, because its resistance is so high, compared to that of two fields in multiple, that it takes very little current. In the case of the loop, Fig. 28, the effects are somewhat different; an open circuit in the upper part of either field will cut that motor out of action until *S* touches *L*, when the loop wire bridges the open circuit, throws the faulty motor with a weak field across the line, and causes the car to jump. The effect of such an open circuit, then, is to make the car start slowly (on one motor), but jump on the loop. If an open circuit takes place in the lower part of either field, the motor is of no use at all, because the fault is beyond the loop wire; and at no stage in the course of the shoe *S* around the rheostat can the current get to the armature of the faulty motor.

**37. Grounds.**—In case of a ground on one motor field, using either a shunt or a loop, it is necessary to disconnect the shunt or loop wire so that it cannot lead the fault to the good motor; also, in case of a grounded armature on either motor, not only must the bad armature be cut out, but its field also; not on account of the fault affecting the other motor, but because as soon as *S* touches *P*, the upper part of the field on the bad motor is in multiple with the upper

part of the field on the good motor, and remains so until *S* touches *L* and cuts out the upper part of the field on both motors.

---

WRONG CONNECTIONS.

**38. Wrong Connections.**—On a car having two motors, two reverse switches, and a shunt or loop, a great many wrong connections may be made, but only the more common ones will be considered here.

**39. *K* and *L* Wires Interchanged.**—By means of Figs. 29 and 30 it can be seen that the effect of interchanging the field wire with either the shunt wire or the loop, is to put them in action throughout the range of the rheostat,

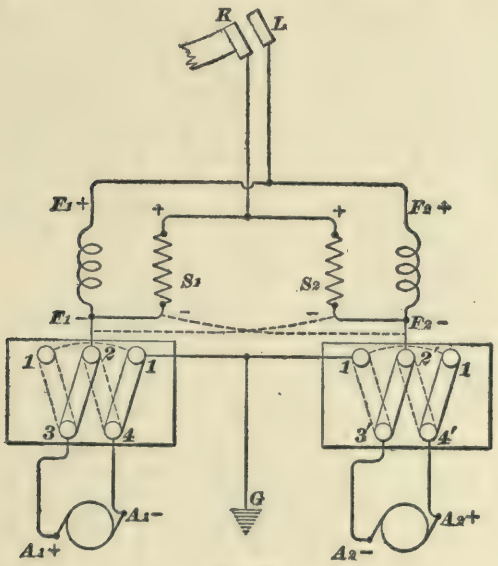



FIG. 29.

thereby, in the case of the loop, Fig. 30, making the car slow-starting and doing away with the increase of speed that ought to be felt in passing to the final position on the rheostat. In the case of the shunt, Fig. 29, the car would start with a

jump when $S$ reaches $L$. As the mix-up in connections has

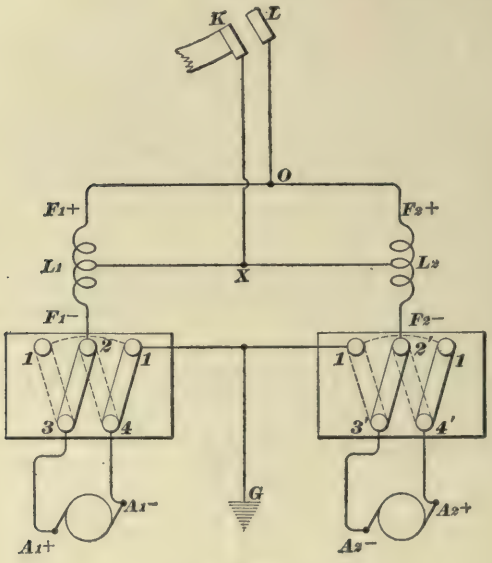



FIG. 30.

only to do with the lower part of the wiring plan, the upper part is left out.

**40. Shunt Terminals Interchanged.**—If the two ends of the shunt on one motor become mixed, it can do no harm, because the polarity of the motor depends in no way on which end of the shunt the current goes in, and, as the shunt is used merely as a by-path for the field current, the current can go into it at either end. It does not matter whether the lower ends of the shunts become confused, as indicated by the dotted lines, provided both motors are in good order, because, so long as this last condition exists, the two fields and the two shunts are always in multiple, whether the lower ends of the two shunts are crossed, as shown in Fig. 31, or not. In case anything happens to one motor, the crossed shunt wires are apt to mislead the man whose job it is to look for the trouble.

**41. Field Terminals Interchanged.**—To confuse the minus and plus field wires on one motor, results simply in reversing the direction in which the armature of that motor will turn, and the trouble can be made right by crossing either the field or the armature leads on that motor; but, when it comes to getting the field leads on one motor mixed with the field leads on the other motor, the result is different, as Fig. 32

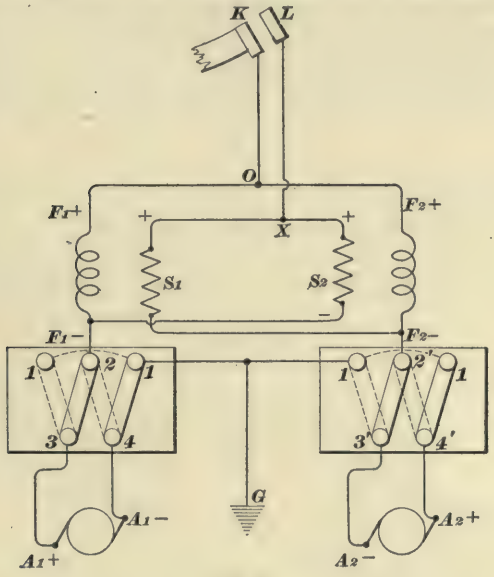



FIG. 31.

will show. Inasmuch as the shunt and loop have nothing to do with the mix-up now to be looked into, and as they make the path of the current harder to follow, they are left out of Fig. 32. In this figure, the current enters at $T$; when it gets to point $x$, it splits, part of it taking the path $x$–$F_1+$–$F_1-$–$2'$–$3'$–$A_2-$–$A_2+$–$4'$–$1$–$G$, and the other part taking the path $x$–$F_2+$–$F_2-$–$2$–$3$–$A_1+$–$A_1-$–$4$–$1$–$G$. It will be noted that each branch of the current goes through the field of one motor and the armature of the other; so long as both motors are in good order, the car will run along the same as if there were no mix-up in the wires at all, but, in case of an open circuit or a ground on any field or armature, both motors

would be thrown out of service. Suppose an open circuit to occur on No. 1 field at *a*; No. 2 armature could then get no current, and No. 1 armature would have no field; No. 1 armature would, therefore, have no counter E. M. F., and there would be a dead short circuit through the path $T$–$x$–$F_2+$–$F_2-$–2–3–$A_1+$–$A_1-$–4–1–$G$.

If the open circuit took place while the car was in motion, with the shoe well around on the rheostat, the main motor fuse would be sure to blow; if the fault occurred while the car was standing still, the car could not be made to move, but the heavy flashing at the shoe would show a large current to

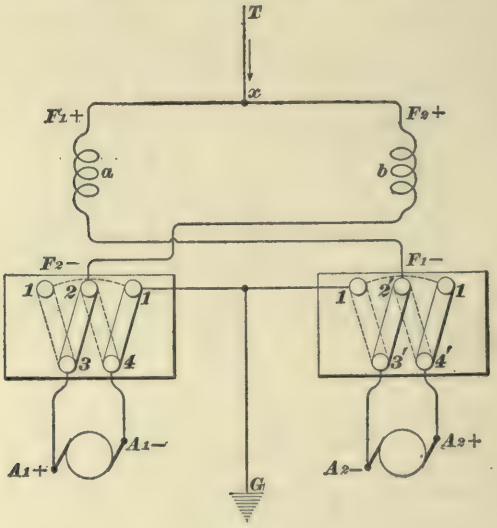



FIG. 32.

be flowing. An open circuit in the No. 2 motor field would open the No. 1 armature circuit so that it would get no current, and rob the No. 1 armature of all field, so that having no counter E. M. F., it would allow an abnormal current to flow through itself and No. 2 field. An open circuit in any brush holder or wire would have the same effect. A ground on the No. 1 field, say at *a*, would put both motors out of service, because the No. 2 armature, to which the No. 1 field is connected, would get no current on account of the ground ahead

of it. A ground on the plus side of either armature would disable the car, but, by throwing the reverse switch to the dotted position, the car could be made to back up. The same symptoms would take place if the No. 2 armature leads were connected to the No. 1 reverse switch, and the No. 1 armature leads to the No. 2 reverse switch. Of course, on the drawing, the leads show up well separated, and there would seem to be very little excuse for getting them mixed; but, under a car, the leads and car wires are, in some places, especially on up-to-date equipments, run side by side, and, in the haste with which cars are generally connected up, it is easy to confuse them.

**42. Armature Leads Interchanged.**—Figs. 33 and 34 show two more very possible confusions. In Fig. 33, No. 2 armature leads have been put into No. 1 reverse switch, and No. 1 armature leads into No. 2 switch. The effect is very

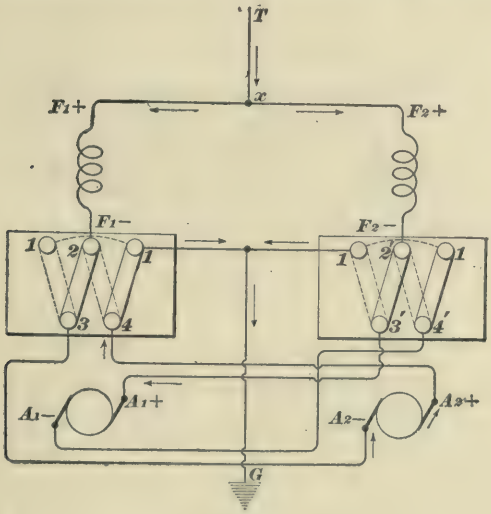



FIG. 33.

much the same as that considered in connection with Fig. 32, where the minus field leads of the two motors have been interchanged. In Fig. 33, as in Fig. 32, there is nothing out

of the way in the action of the car as long as both motors are in good order; the current splits at $x$, one part taking the path $T$–$x$–$F_1+$–$F_1-$–2–3–$A_2-$–$A_2+$–4–1–$G$; the other part takes the path $T$–$x$–$F_2+$–$F_2-$–2′–3′–$A_1+$–$A_1-$–4′–1–$G$; in both circuits, the field of one motor is in series with the armature of the other, so that if a fault of any kind takes place in one motor, both motors are put out of use.

**43.** In Fig. 34, the $A_1-$ lead of No. 1 motor has been mixed with the $A_2-$ lead of No. 2 motor, with the result that the car cannot be made to move at all, because neither motor circuit is complete, and no current can flow. There is a local

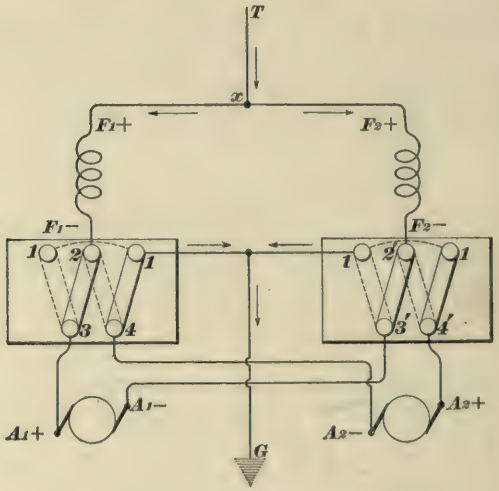



FIG. 34.

circuit $x$–$F_1+$–$F_1-$–2–3–$A_1+$–$A_1-$–3′–2′–$F_2-$–$F_2+$–$x$, but as this circuit does not reach the ground, no current can flow in it.

**44.** It would be possible for us to draw plans and follow the path of the current for many more wrong connections possible in connecting up a car equipped with one rheostat, two motors, and two reverse switches, but it is hoped that by this time the student can do it for himself.

MULTIPLE CONTROL—SIMPLE PLATFORM CONTROLLER.

**45.** There is very little difference between a rheostat, like the one that we have just considered, and a platform controller. With a rheostat, Fig. 35, the resistance is cut out gradually, by the shoe moving around the half circle *P R K*; with a controller, the resistance is cut out in steps.

**46.** Fig. 36 gives an idea as to how a controller does its work. *R* is a resistance divided into two parts; one part lies between *1R* and *2R*, and the other part between *2R* and *3R*; *F* and *A* are the field and armature of a dynamo that is to furnish the current for running the motor whose field and armature are *F* and *A'*; *D* is a round casting fitted on a wooden drum provided with an iron shaft that turns in

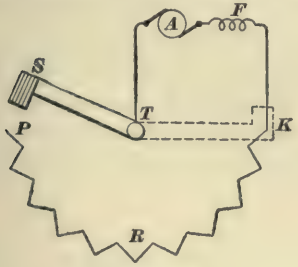



FIG. 35.

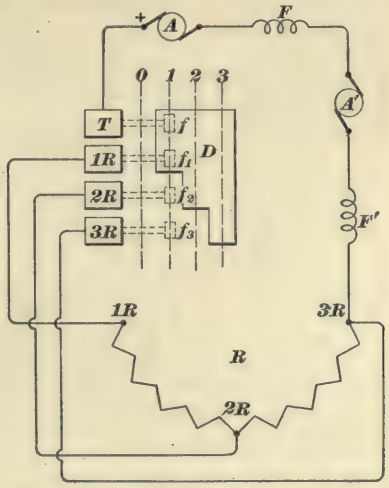



FIG. 36.

bearings; *T*, *1R*, *2R*, and *3R*, in the upper part of the figure, are brass finger stands, on each of which is a spring-pressed finger, hanging over *D*, as indicated by the dotted line and marked in the figure $f$, $f_1$, $f_2$, $f_3$. A wire is connected to each of the finger stands. Stand *T* is connected to the trolley wire; stands *1R*, *2R*, and *3R* are connected to the resistance coil at points marked with the corresponding letters. On the controller shown in Fig. 36, there are four notches, indicated by the dotted lines, marked *0*, *1*, *2*, *3*. The line marked *0* denotes the off-position, and no current can pass

through the circuit, because the trolley finger *f* hangs in the air, as shown in Fig. 37 (*a*), without touching the contact plate *c* mounted on the drum *D*. Dotted line No. *1* denotes the first notch, and fingers *f* and $f_1$ touch the contact plate on drum *D*, as shown in Fig. 37 (*b*). The circuit being, therefore, closed, the current can flow through the path *A*+ –*T*–*f*–*D*–$f_1$–*1R*–*1R*–*2R*–*3R*–*F*'–*A*'–*F*–*A*. Dotted line No. *2* denotes the second notch where the drum is turned until finger $f_2$ makes contact; the path of the current is then *A*+ –*T*–*f*–*D*–$f_2$–*2R*–*2R*–*3R*–*F*'–*A*'–*F*–*A*. On the second notch, when the current gets to drum *D*, it finds two paths by means of which it can reach point *2R* on the resistance coil; one path is $f_1$–*1R*–*1R*–*2R*, and the other path is $f_2$–*2R*–*2R*. The first path has a part of the resistance coil in it, and the second path (i. e., car wire *2R*–*2R*) has no resistance to speak of, whatever. Wire *2R*–*2R* then short-circuits a part of the resistance. When the drum is turned another notch, and finger $f_3$ comes into contact, the path of the current is *A*+ – *T*–*f*–*D*–$f_3$–*3R*–*3R*–*F*'–*A*'–*F*–*A*. Wire *3R*–*3R* short-circuits the whole resistance in *R*, and the motor runs on full field directly across the line, just as it does in Fig. 2, when *S* touches *K*.

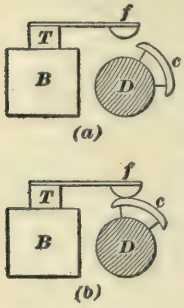


FIG. 37.

**47. Number of Notches.**—There is no limit to the number of notches that such a controller can have; but there must be as many steps in the contact plate on drum *D* as there are parts in the resistance. The more parts *R* is divided into, the smaller will be the part cut out on each notch and the more smoothly will the car pick up its speed and the less flashing will there be at the controller.

**48. Reverse Switch and Controller.**—Fig. 38 shows how a reverse switch may be connected with such a controller; but in actual practice, when these old controllers were in use, it was customary to arrange them to do the

reversing, as indicated in Fig. 39. In this figure, the off-position is in the center, and the controller handle, when in this position, points straight ahead. On each side of the off-position, the drum is fitted with a set of contact plates; the two sets of plates do not touch each other. When the controller handle is moved to the right, the fingers overhanging from stands $T$, $R_1$, $R_2$, etc. make contact with plates $d+$, $c+$, $e+$, $h+$, $i+$, and the car goes ahead. When the controller handle is turned to the left, the fingers make contact with plates $d-$, $c-$, $e-$, $h-$, $i-$, and the car backs up. The reason for this is found in the connections of the drum contact plates. On the plus side of the drum, $d+$ and $c+$ are connected together, as are $e+$ and $h+$, the current going into the armatures through their plus leads. On the minus side of the drum, $d-$ and $c-$ are connected together, as are $e-$ and $i-$, so that the current goes into the armatures through their minus leads. The armature connections being reversed, and those of the field being the same in the two

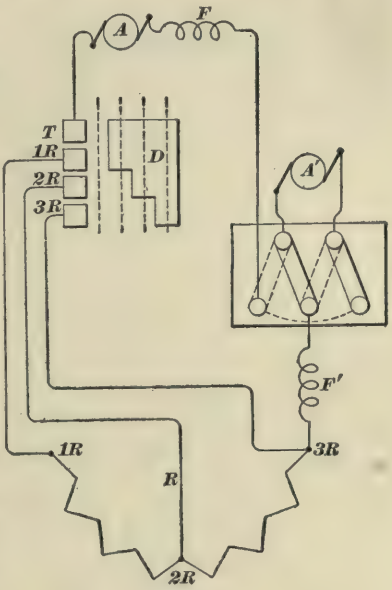



FIG. 38.

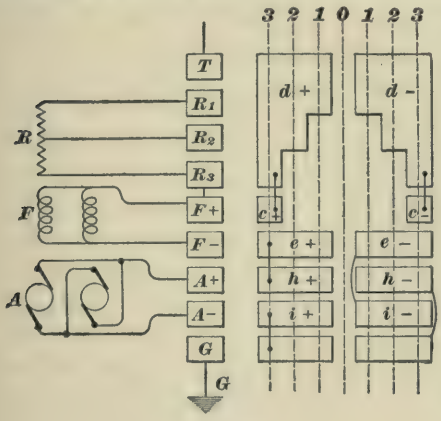



FIG. 39.

cases, the armature changes its direction of rotation, and the car its direction of motion.

**49. The Cut-Out Switch.**—In the days when electric cars were equipped with the straight-multiple system of control, it was the practice to cut out a faulty motor by disconnecting its leads. This practice was done away with by the introduction of the old-style cut-out box that usually found a place under the car seat. Fig. 40 will give a very fair idea of how a cut-out box works. There are three positions for the drum, as indicated by the dotted lines *1*, *2*, *3*; on the first position, both motors are in, and the current, when it gets to finger stand $T'$ on the cut-out box, splits into two parts; one part goes through the No. 1 motor by way of path $T'$–$X$–$F_1$+–$F_1$+–$F_1$–– $F_1$– –$Y$–$A_1$+ –$A_1$+ – $A_1$––$G$; the other part goes through No. 2 motor by way of path $T'$–$X$–$F_2$+–$F_2$+–$F_2$–– $F_2$– –$Z$–$A_2$– –$A_2$– – $A_2$+ –$G$. When the cut-out is turned to the second notch, there being no contact plates on the lower part of the cut-out drum, the current cannot get to the No. 2 motor, so this

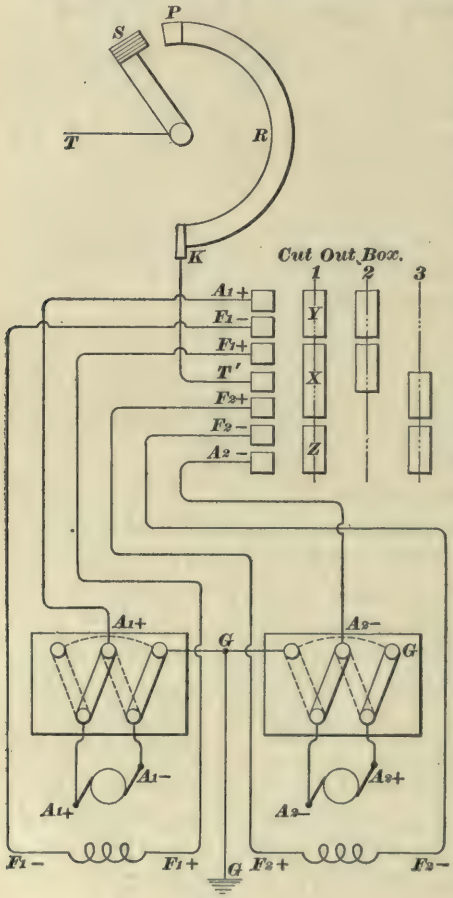



FIG. 40.

motor is cut out. On the third notch, the No. 1 motor is cut out for the same reason. On an actual cut-out box, the No. 1 position is in the center, and the Nos. 2 and 3 on either side; so that to cut out one motor, the cut-out drum must be turned to the right; and to cut out the other motor, the drum must be turned to the left. Both motors cannot be cut out at the same time.

---

### OLD-RHEOSTAT SERIES CONTROL.

**50. Difference Between Series and Multiple Control.**—Most of the faults and failings of multiple control having been considered, it will be well before taking up the consideration of series-multiple control to point out the main feature of straight series control. Series control was never a system very generally adopted, but, as it is embodied to a great degree in all up-to-date series-multiple controllers, a familiarity with its details will not be out of place. In straight multiple control, the two motors are always in multiple; in straight series control, the two motors are always in series. In other words, in multiple control, each motor has its own circuit, and current can flow in one motor whether there is an open circuit in the other motor or not; in series control, the current must pass out of one motor into the other, so that an open circuit in either of the motors puts both motors out of action until the fault is removed, or the motor is cut out.

**51. Path of the Current.**—Fig. 41 is a plan of the wiring for one rheostat, two reverse switches, and two motors. It is almost needless to say that either the series or the multiple systems require at least two motors, for a single motor cannot be either in series or in multiple with itself. In Fig. 41, all letters and figures have the usual meaning, and the path of the current is $T$–$T'$–$S$–$P$–$R$–$K$–$F_1$+–$F_1$––$A_1$+–$A_1$––$F_2$+–$F_2$––$A_2$––$A_2$+–$G$. It must be noted that the two reverse switches bear a different relation to each other from what they did when the motors were in multiple, as

shown in Fig. 40. In that figure, the No. 1 posts on both reverse switches were all connected together and to the ground, but in Fig. 41, only one reverse switch is grounded;

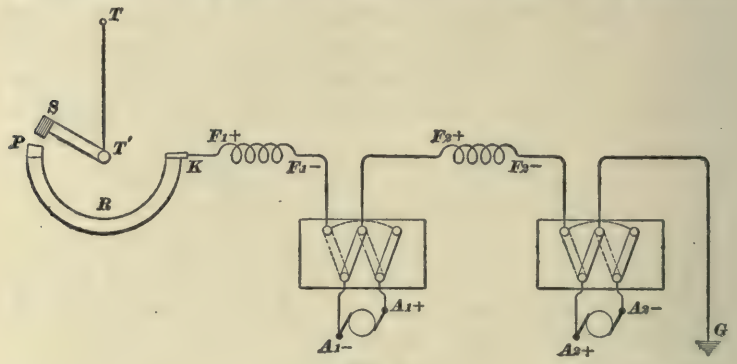



FIG. 41.

this is because the motors are in series. If both the reverse switches were grounded, the current would pass through one motor only, and to the ground without going through the other motor at all, and No. 2 motor would be cut out.

**52. The Cut-Out Switch.**—The fact that an open circuit on either motor opens the main circuit and puts both

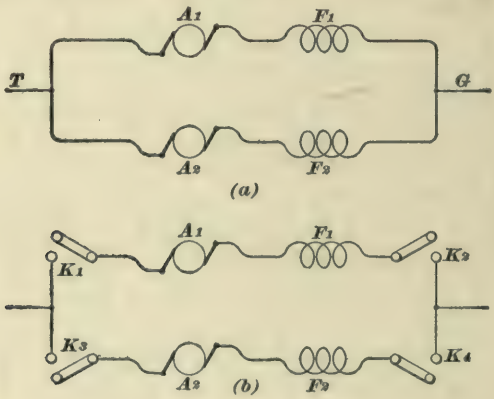



FIG. 42.

motors out of service, makes it clear that a cut-out switch of some sort would be a very good thing on such an equipment.

A feature that a cut-out of this description possesses that is not to be found in the cut-out (Fig. 40) used in cutting out one of two motors that are in multiple is, that when the two motors are in multiple, the cut-out has only to open completely the circuit on the bad motor; but, if the two motors

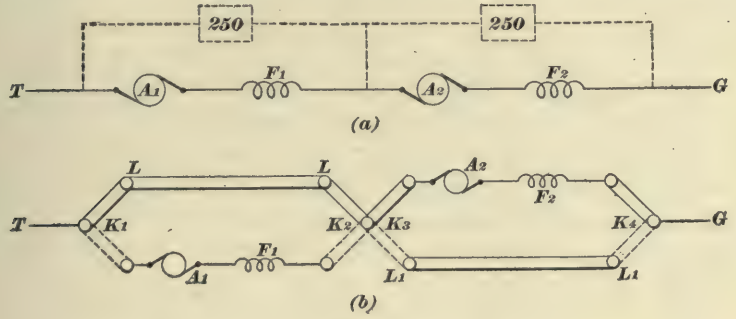



FIG. 43.

are in series, the cut-out must not only remove the bad motor entirely from the circuit, but it must replace it by a bridge of metal so that in all cases the current can reach and pass through the motor that has not been cut out. Figs. 42 and 43 show this distinguishing feature in a very simple way.

**53. Series Cut-Out and Multiple Cut-Out.**—In Fig. 42 (*a*), two motors are shown in multiple without any cut-out switches. In Fig. 42 (*b*), two motors are shown in multiple, and each motor has two simple switches by means of which both ends of the motor can be cut loose from the circuit. It has been explained elsewhere why it is necessary to cut out both ends of the motor. In the figure, the four switches $K_1$, $K_2$, $K_3$, and $K_4$ are shown to be open, so that both motors are cut out. In an actual cut-out, all four switches are together on the same baseboard, and they are so fixed that they interlock. $K_1$ and $K_2$ are operated by one handle, $K_3$ and $K_4$ by another handle; the first pair forms the cut-out of No. 1 motor, and the second pair that of motor No. 2. If No. 1 motor is cut out, the handle of No. 2 motor cannot be moved,

and vice versa. It can readily be seen that there would be no occasion to cut out both motors, as the car would then be unable to run. When the two motors are in multiple, then, the cut-out switch just opens the motor circuit at both ends. Fig. 43 (*a*) shows the path of the current through two motors in series, and Fig. 43 (*b*) shows how the cut-out switches throw the bad motor out of the circuit, and put a strip of copper $L\,L$, and $L_1\,L_1$, in its place.

For the sake of clearness, the switches $K_1, K_2$, $K_3$, and $K_4$ are shown widely separated, while, in the actual device, they are close together so that their handles interlock. These switches, when they are in the full-line position shown in Fig. 43 (*b*), cut out No. 1 motor, and the current passes through copper strip $L\,L$ to No. 2 motor, through it to the ground by way of path $T$–$K_1$–$L$–$L$–$K_2$–$K_3$–$A_2$–$F_2$–$K_4$–$G$. If all the switches be thrown to the dotted position, No. 2 motor is cut off entirely, and the course of the current from $T$ to $G$ is $T$–$K_1$–$A_1$–$F_1$–$K_2$–$K_3$–$L_1$–$L_1$–$K_4$–$G$. Switches $K_1$ and $K_2$ are operated by the same handle, and form the No. 1 cut-out; switches $K_3$ and $K_4$ are operated by the same handle, and form No. 2 cut-out. It is easy to see that if the cut-outs were opened just far enough to clear one set of contacts before touching the other set, the circuit would be open; for this reason, the switch blades are made so that they make contact with $L\,L$ before they break an arc. They are intended to be used only when the current is off. Their blades will surely be destroyed by any attempt to use them while a current is passing.

**54. A Type of Series Cut-Out.**—Fig. 44 shows the connections on a series cut-out box. There are three positions of the drum, as indicated by the numbered dotted lines. On the first notch both motors are in, and the path of the current is $T$–$S$–$P$–$R$–$K$–$T'$–$a$–$F_1$+–$F_1$+–$F_1$–$F_1$–$b$–$A_1$+–$2$–$3$–$A_1$+–$A_1$–$4$–$1$–$A_1$–$d$–$F_2$+–$F_2$+–$F_2$–$F_2$–$c$–$A_2$–$2'$–$3'$–$A_2$–$A_2$+–$4'$–$1'$–$1'$–$G$. On the second notch, No. 2 motor is cut out, and its place is taken by copper connections $h\,i$. On the third notch, No. 1 motor is cut out, and its place is taken

by strip *j k*. On an actual cut-out, the first notch is in the center and the other two notches are on either side.

**55.** In connection with the control of motors, it may be well at this point to review a few important points in connection with voltage. A great many people have an idea that a dynamo generates electricity. A dynamo does not generate electricity any more than a pump generates water. Electricity exists just as water does; the dynamo raises the pressure of the electricity just as the pump raises the pressure of water. After the pump has acted on the water, the water has a *head*, or is raised to a higher level; after the dynamo has acted on electricity, the electricity has E. M. F., or *voltage*. When a pump forces water through a pipe line, it does so against a certain amount of resistance due to the friction of the pipe walls and to the bends in the pipe; the greater this resistance, the less water can the pump send through the system, because the pressure generated by the pump is spent in overcoming this resistance. Wherever this

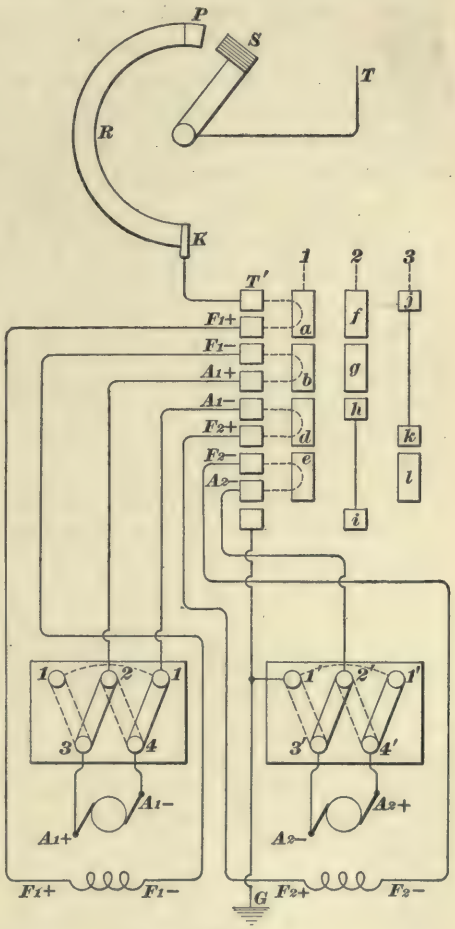



FIG. 44.

resistance is greatest, the greatest drop in the pressure takes place. So in an electric circuit; from the trolley wire to the ground, the drop in pressure or voltage is, say, 500 volts. If the motor circuit on a car is closed, this pressure of 500 volts sends a current through the car; if the motors are in series, as shown in Fig. 43 (*a*), the voltage spends or distributes itself according to the resistance of the several parts of the circuit. Part of the voltage is spent in forcing the current through the resistance of the rheostat; part in sending it through the field coils; and part in sending it through not only against the resistance, but also against the counter E. M. F. of the two armatures. When the rheostat shoe reaches its final position, and all the rheostat is cut out, the voltage divides itself equally between the two motors, each motor getting a drop of 250 volts across its outside terminals.

In other words, if, while the car is under full headway, two voltmeters be placed as shown by the dotted lines in Fig. 43 (*a*), each voltmeter will register 250 volts, if the line voltage is 500. It is readily seen, then, that if anything happens to one motor so that it has to be cut out, the other motor, as soon as the rheostat shoe reaches its final position, is across the line alone. Now, motors that are intended to run two in series are wound for only 250 volts each, and as soon as one of them is put straight across the line, it is subjected to a voltage twice as great as it should get, with the result that it soon breaks down from the abuse. On a car equipped with two motors connected in series, it is the custom when one motor breaks down so that it has to be cut out, to use only a part of the rheostat to run the car to the house. If it is tried to run a trip on one motor, by using only a part of the rheostat, the tax on the rheostat is so great that it is very apt to give out before the trip is completed. The idea of *always* running the two motors in series has never seemed to take a strong hold on street-railroad men, for the advantages claimed are doubtful; but the idea of running them part of the time in series has been accepted and will be considered later.

# CAR EQUIPMENT.

(PART 6.)

## GENERAL ELECTRIC SYSTEM.

### GENERAL ELECTRIC MOTORS

#### GENERAL ELECTRIC 1000 MOTOR.

**1.** The General Electric motor, like any other motor, is made up of several well defined parts. These parts include the *frame*, the *field coils*, the *armature*, the *brush holders*, and last, but not least, the *bearings*.

**2. Frame.**—The *frame* of the G. E. 1000 motor, shown at *Z*, *Z*, Figs. 1 and 2, is eight-sided in shape, as seen from the end, and is in two parts, hinged together by means of a hinge pin at *B*, in Fig. 3, which is drawn to show the general method of hinging a number of motors of this type, and does not apply to this motor alone. On one half of the frame, two pairs of lugs are cast; on the other half of the frame, one pair of lugs is cast. In some motors, the two single lugs go between the two pairs of lugs, and the hinge pin passes through a hole drilled in all three of the lugs. In this motor, a link *e* passes between the upper lugs and through the lower lug. The hinge pin *B* passes through *e* and the two lugs *a*, *a'* on the upper field frame, and the nut *n* serves



For notice of the copyright, see page immediately following the title page.

to clamp the two frames together. The frame is made of a special steel that carries magnetic lines of force better than

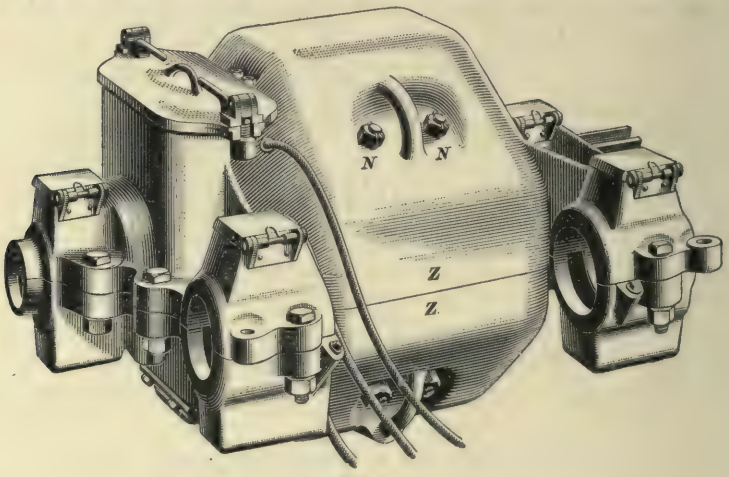



FIG. 1.

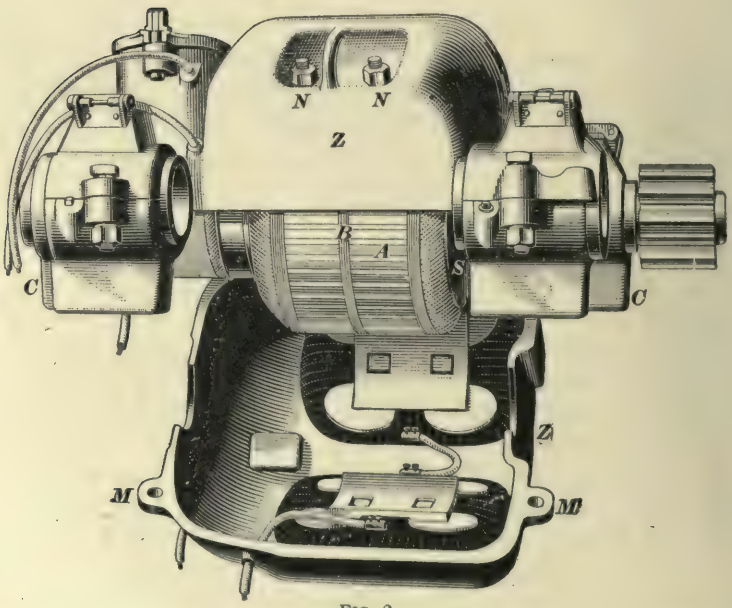



FIG. 2.

cast iron, but not quite so well as wrought iron. Cast steel

is used instead of wrought iron, because the latter cannot be forged into the shape that a street-car motor should have. That zone of the frame which is in line with the pole pieces *P*, *P*, *P*, *P*, Fig. 3, is made thick enough to carry the required number of lines of force, but all other parts of the frame are made as thin as due strength will permit. When the motor is closed, Fig. 1, the two halves are held together by means of the hinge bolts and two bolts passing through the holes shown at *M*, *M*, Fig. 2. To open the motor, these two bolts must be removed. The frame is made so that the lower half may be let down into the pit, in order that a field coil or an

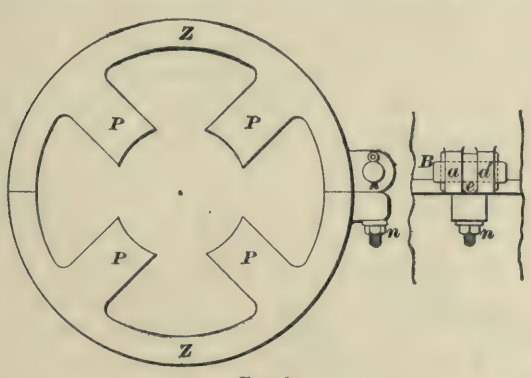



FIG. 3.

armature may be removed without raising the car and drawing out the truck, and to avoid having the pit men go inside the car to work.

To open up a motor frame, it is a good plan to have a pump jack with a cradle on top of the rack; the jack is raised till the weight is taken off the motor bolts, so they can be loosened and taken out; the jack is then lowered and the lower half of the frame lowers with it. If the bolts that secure the armature caps *C*, *C* to the top half of the frame are left in, the caps hold the armature up so that the lower half of the frame goes down without it; but, if these bolts are taken out, thereby releasing the caps, there is nothing to hold the armature up, and it falls with the lower half of the frame.

This is a very convenient arrangement, because if anything happens to either a top or a bottom field, the faulty field can be gotten at without handling the armature at all. Also, the armature can be taken out without touching any of the fields. If there is trouble in a top field, the lower shell is let down with the armature in it; if there is a fault in the lower fields, the armature is left in the top shell.

An armature can be taken out in either of two ways: It can be lowered with the bottom shell and rolled out on a board, or it can be left in the top shell until the jack is shifted and the cradle run up to take it; in such a case, an old blanket should be thrown over the cradle, to avoid bruising any of the band wires on the armature. In the bottom of the lower shell under the commutator is a handhole, by means of which the inside of the motor can be inspected, and through which all dust and dirt can be blown out with a hand bellows. If this hole is used as much as it ought to be, the bearings will never run long enough to let the armature down on the pole pieces, because the inspector can at any time see how much air gap there is between the armature core and the lower pole pieces. There are four pole pieces, which are flanged and also provided with projecting ears, as shown in Fig. 4, and bolted to the frame by means of bolts *N*, *N*, Figs. 1 and 2. The flanges and ears serve to hold the field coils in place.

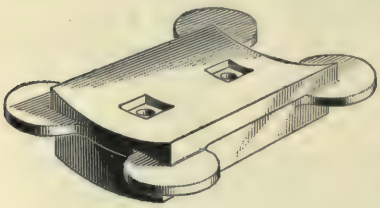


FIG. 4.

**3. Field Coils.**—The G. E. 1000 motor, like all up-to-date street-car motors, has four field coils. One field coil goes on each pole piece. These field coils are wound on a wooden form, the inside of which is shaped to correspond with the outside of the field coil. As the coil is being wound, the winder puts on a sort of plastic insulating paste. When the coil is done, it is put in an oven and baked until it becomes such a solid mass that a fall on the floor will not

cause it to lose its shape. After coming out of the oven, it is served with several layers of pliable insulation. This course of treatment varies in different places in detail, but, in general, is about the same and consists mainly of several applications of mica, tape, braid soaked in varnish, fiber, asbestos, and, at last, a course of good stout tape, which is given several coats of P. & B. paint or some other compound that will take a glaze and throw off water. This motor, like many other motors, is, from the nature of its frame, practically waterproof, but there are some conditions under which the water will find its way in a little at a time, so the field insulation must be designed with this condition in mind. The G. E. 1000-motor field coil consists of 145 turns of No. 4 B. & S. gauge double cotton-covered wire, so that the whole field, four coils, has in it $4 \times 145$ turns $= 580$ turns of wire. The fields all look alike and the terminals also look alike, so that great care must be taken not to get the coils turned end for end when putting them into the motor; everything depends on getting them into the motor right, for after they are once in, there is only one way to connect them, as the terminals that should connect together come right opposite each other.

There is only one rule to bear in mind when connecting up the fields on a four-field motor, and that is, always be certain to get an inside end connected to an inside end. The two ends can be readily distinguished by the way in which they come out of the coil. The inside end, having to pass across every layer of wire in the coil, is heavily insulated, and this heavy insulation raises a bump. The rule in other words, then, would be to connect the terminal that has a bump under it to a terminal that also has a bump under it, and it is then certain that two inside ends are being connected together. The fields must then be put into the motor so that terminals with bumps come opposite each other, and those with no bumps the same. It is not an easy matter to get a field coil in, top side down, because the bottom side of the field coil is made so as to fit the curve on the inside of the motor frame. However, it is sometimes done, and it

must be looked out for. When the field coils are once connected up right inside of the motor, the next point of confusion lies in the bringing out of the leads; they must not be confused with the armature leads. The armature leads are, in most cases, above the field leads, and one on each side of the motor, but this is not always the case, and, if there is any doubt, it is best to run the hand inside of the motor and trace the lead from its bushing, through which it leaves the frame, to whatever part of the motor it goes. If it goes to a brush holder, it belongs to the armature; if it goes to a field coil, it is a field lead.

**4. Armature.**—The *armature A*, in Fig. 2, is the part that turns, and consists of several parts, among which are the *core*, *commutator*, *shaft*, *winding*, *shield*, and the *grease rings* and *band wires*. Fig. 5 shows an armature core and shaft. The core is built up of toothed iron disks *D*, keyed to the shaft *S S* so that they cannot turn round, and are

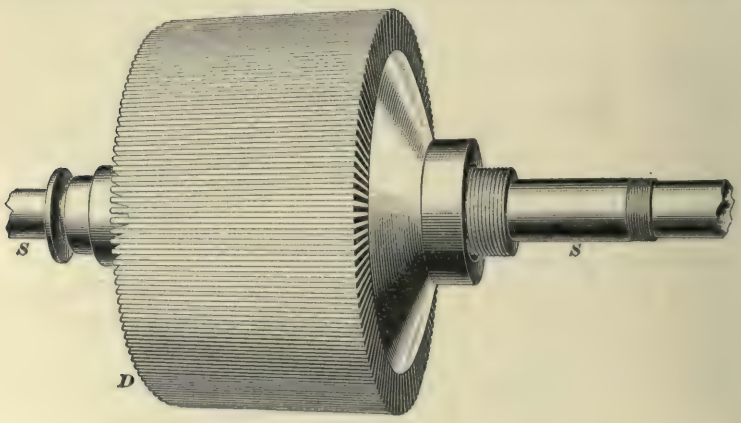



FIG. 5.

clamped up against a shoulder at one end of the core by means of a compression plate and nut at the other end. These disks, or plates, or washers, are forced into a solid and compact mass. A core thus built up is called a *laminated* core, and is so called because the Latin word *lamina* means a

thin plate. The core is laminated in order to do away with the eddy currents, which would cause a solid core to get hot and burn all the insulation off the wires that lie in the slots on the surface of the core. Fig. 5 indicates the general appearance of the G. E. 1000 core before the coils are applied.

The disks forming the core are provided with a number of teeth, and when the disks are assembled on the shaft, a corresponding number of slots are formed. The wire is wound up into coils on forms, and these coils are made to hold their shape by winding them with tape. Fig. 6 shows the shape of a coil suitable for the core shown in Fig. 5. The straight portions $a\,a'$, $b\,b'$ lie in the slots and the ends are given the shape shown, so that the different coils may cross each other without interfering. The terminals $c$, $c'$ are connected to the commutator. Fig. 7 shows a railway motor armature with the coils placed in position in the slots and partly connected to the commutator. This figure shows clearly how the terminals of the coils are brought to the commutator, one half the connections being shown in place. The remaining terminals are shown bent back out of the way, to be connected later into the upper part of the slot shown in each

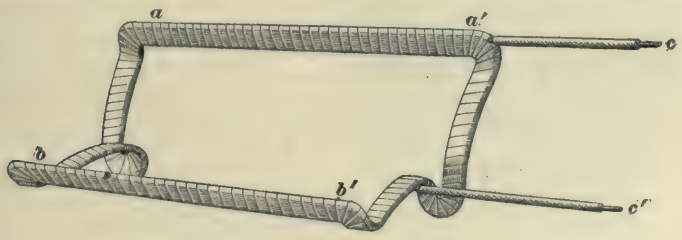



FIG. 6.

commutator bar. In this armature, the ends of the coils $E$ project out over the end of the armature core instead of bending down as in Fig. 6. Both of these methods of arranging the coils are in common use, the one shown in Fig. 7 being sometimes called a *straight-out* winding.

The G. E. 1000 core has 93 slots and it takes 93 coils to fill these slots. Each coil consists of four turns of No. 9

B. & S. gauge double cotton-covered wire, so there are eight wires in each slot and $8 \times 93 = 744$ wires running the full length of the core. When an armature turns around very fast, there is a great tendency for the wires to fly out of the slots, not only on account of the centrifugal force, but on account of the drag that the pole pieces exert on the wires. To hold the wires in place, there are provided the bands *B*, Fig. 2, and the shield *S*. The bands are three in number, and consist of 18 or 20 turns of No. 16 or 18 B. & S. gauge phosphor bronze or steel wire, secured in place by clips of sheet copper laid under and then bent over, as shown in Fig. 8 (*a*). The whole surface of the band is then soldered. The shield is a brass or iron cap curved to fit the shape of the ends of the coils and screwed on to a shoulder on the shaft. This shield has an insulating washer on the inside, next to the coils, so that it cannot bruise the coils when it is screwed home. If the shield is left off, the coils must be tied down to the shaft with strings, or they will raise on the end, and

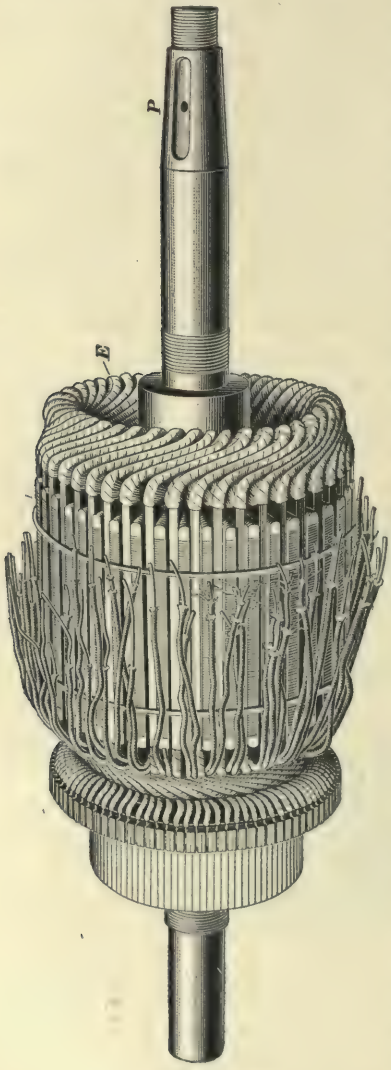



FIG. 7.

they are apt to rub the pole pieces the first severe pull they get.

**5. Commutator.**—One of the most important parts of an armature is the *commutator*. The principle of the commutator and its office and action have been discussed in *Motor Principles*, Part 1, and nothing more will be said here than to show how a commutator is made. The commutator in its simplest form is shown in Fig. 8 (*b*) and (*c*), where *A* is a wooden drum and *B* a brass pipe forced over it. *A* has a hole in it, through which the armature shaft passes. If the pipe be sawed into strips, as shown in Fig. 8 (*c*), the result is a commutator in every sense of the word. The terminals of the armature coils *c*, *c* are connected to these strips as shown. Of course, such a crude article as this would not do for a street-car motor whose commutator must be made of iron, copper, and mica.

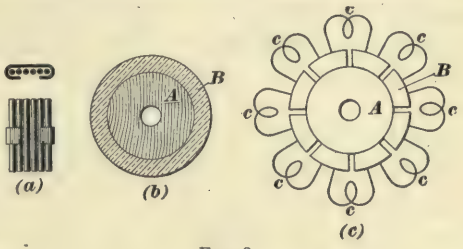



FIG. 8.

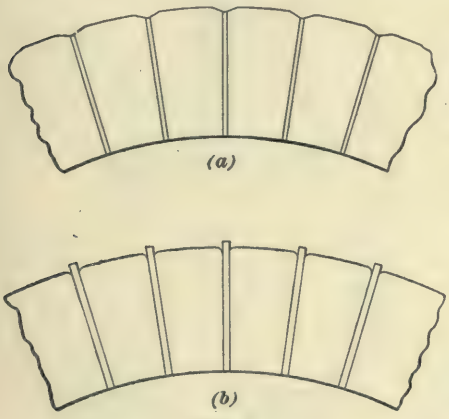



FIG. 9.

The principal parts of an up-to-date commutator are the bars, the mica rings and bodies, iron rings and nuts, and the shell. The copper bars or segments are made of hard-drawn or drop-forged copper, and they must be of uniform quality, so that the commutator will wear evenly. The mica bodies or side insulations are

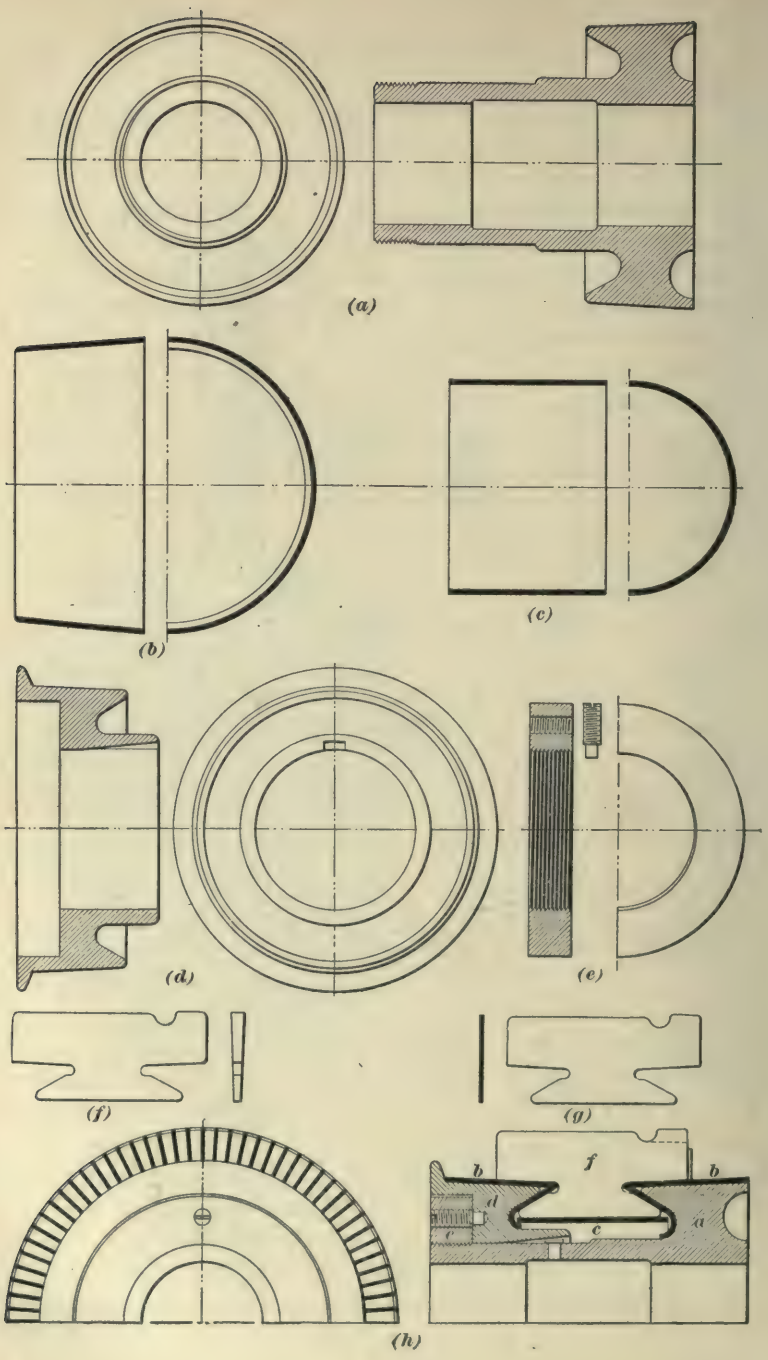



FIG. 10.

of the same shape as the bars, and there are just as many of them, one body going in between every two bars so that they cannot touch each other. The mica must be so selected as to wear at the same rate as the copper, otherwise the commutator will soon become rough. The mica bodies must have a certain thickness relative to that of the bar, or the wear will be bad. Fig. 9 (*a*) shows how the commutator wears when the mica bodies are too soft or thin; Fig. 9 (*b*) shows how it wears when the bodies are too hard or too thick. In either case, the brushes spark badly and wear the bars away very fast.

**6. Construction of Commutator.**—Fig. 10 (*a*), (*b*), (*c*), (*d*), (*e*), (*f*), (*g*), and (*h*) show the parts of which a G. E. 1000 commutator is made up; (*h*) shows the location of the various parts after the commutator is put together. (*a*) is the shell proper and it must be made of steel, brass, or malleable iron, so that it will not crack when it is put under the pressure necessary to hold the bars and bodies in place; (*b*) is a mica cone ring that fits into the head of shell, as shown at *b* in the assembled view (*h*); (*c*) is a mica sleeve that slips under the segments, as shown at *c* in (*h*); (*d*) is a cone ring made of the same stuff as shell (*a*); this cone ring goes on to the shell to form its other head, and, after receiving a mica cone ring like (*b*), is shoved home against the end of the bars and bodies by means of a nut (*e*), which threads on to the shell (*a*). One of the bars is shown at (*f*), and (*g*) shows one of the mica insulations used between the bars. Fig. 11 shows these several parts put in place,

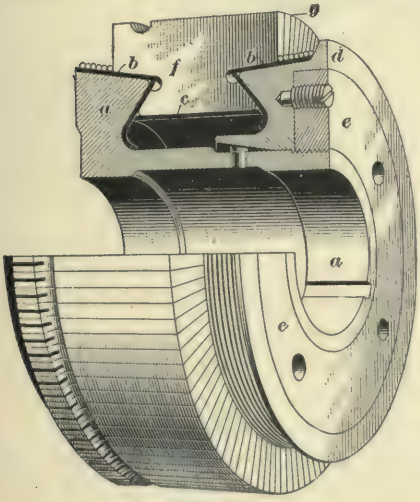



FIG. 11.

and indicates clearly the method of construction. Fig. 12 shows the mica bodies and copper bars all ready to be put on the shell. The G. E. 1000 commutator is built up of hard-drawn copper bars, and there are 93 of them, one for each

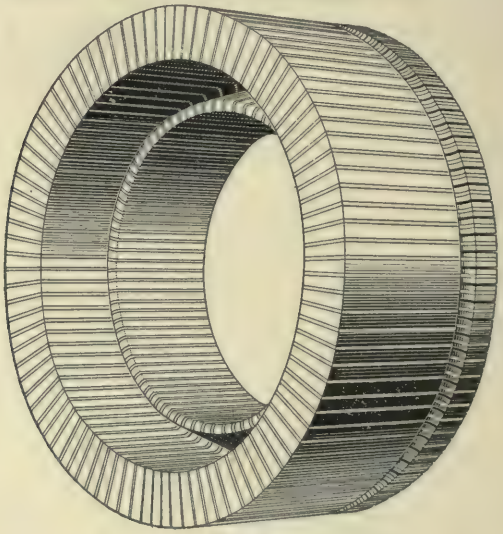


FIG. 12.

coil in the armature. The beginning of one coil and the end of the coil next to it are brought down to the same bar, so that the coils all around the armature form a closed circuit, as shown in Fig. 8 (*c*).

**7. Brush Holder.**—The brush holder is, as the name implies, a device for holding the motor brushes, and is one of the most important parts about a motor, because, as soon as it gets the least bit out of order, the motor begins to cut up. Fig. 13 shows a carbon brush such as is used on motors of today; street-car motor brushes are always made of carbon, because they spark less than copper brushes; they spark less than copper brushes because their resistance is so high that they will not let the short-circuited coils

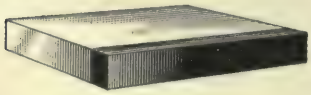


FIG. 13.

passing under them send a very large current through them. A copper brush is more efficient because it can carry the current easier than a carbon brush, and gives rise to a much less loss due to heating.

On all electric machines that handle large currents, and, therefore, are of lower voltage, copper brushes are used, for several reasons. One reason is that a carbon brush of the size required to carry a heavy current would be so large that there would not be room for it on the commutator. Another reason is that heat losses increase very rapidly when the current is increased, and, in some cases, for this reason, the use of a carbon brush would be out of the question. A copper brush can be used on lighting machines and on other machines whose load does not go up and down in big jumps, because the changes in the load are not so sudden but that the brushes may be shifted to a place where they do not spark. Such a place always exists if the machine is in good order and if the load is not too much above the limit, and such a machine always has a device for shifting the brushes back and forth as the change in the load may require.

On a street-car motor, the conditions are very different; the load, with little or no notice, jumps from nothing to a value of 50 or 100 per cent. above the motor's rating, and the brushes cannot be shifted, because there is no device to shift them with. Assuming that such a device could be put in place, it would be of little or no use, because the changes of load are so sudden and violent that a man could not handle the shifter quickly enough or with enough accuracy to do any good.

As a rule, carbon brushes are used on machines of 500 volts or over, because, on such machines, the current is comparatively low. Take, for instance, a 100-horsepower, 500-volt motor and a 100-horsepower, 100-volt motor, and let us compare the sizes of the carbon brushes that would be required to carry the full load current in the two cases. A 100-horsepower, 500-volt motor, at full load, would call for a current of 150 amperes; a 100-horsepower, 100-volt motor would, at full load, call for a current of about 750 amperes. On up-to-

date street-car motors, the brushes are so made that they have about 1 inch of cross-section for every 40 amperes of current flowing through them at full load. The 100-horsepower, 500-volt motor, having a full-load current of 150 amperes, would call for 3.75 square inches of cross-section in the brush; whereas, the 100-horsepower, 100-volt motor, with its current of 750 amperes, would call for a brush having 18.5 square inches of cross-section; this would mean a brush 1 inch thick and $18\frac{1}{2}$ inches long, which would, of course, be out of the question.

**8.** Fig. 14 shows the brush holder used on the G. E. 1000 motor. In this figure, *A* is the commutator, *B*, *B* the motor brushes, *H*, *H* the brush holders proper, made of brass, *W*

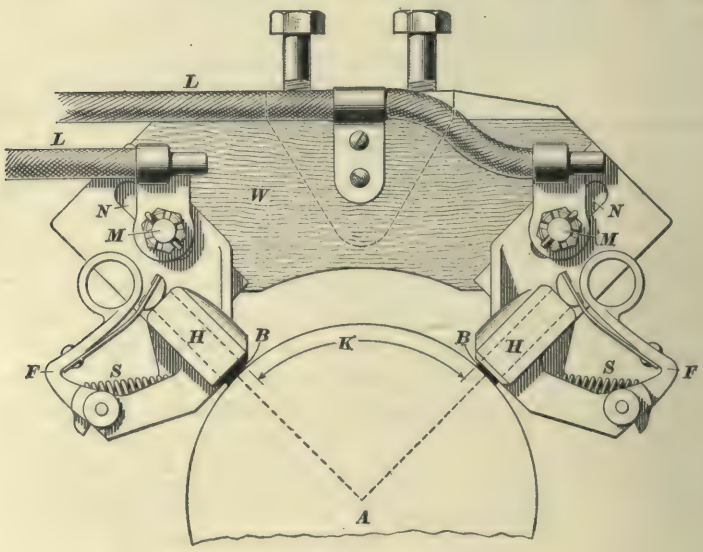



FIG. 14.

is a wooden yoke that is fastened to the motor frame by means of a casting not shown, *N*, *N* slots in the brush holders, and *M*, *M* bolts provided for sliding the brush holders towards or away from the commutator. The two brush leads have brass terminals that are secured also by bolts *M*, *M*. The

wooden yoke is made of well seasoned maple that has been boiled in paraffin so that it can take in no moisture. It is then treated with some insulating compound and rubbed down to a smooth finish so that it will hold no carbon dust or water on its surface. Wood, for a brush yoke, must be chosen with care and well treated or the heat of the motor will cause it to shrink or warp out of shape, and thereby pull the brush holders out of line, causing sparking and rapid wear of the brushes. *S*, *S* are two tension springs that pull down on fingers *F*, *F*, and press the brushes against the commutator. It must be noticed that both brushes point directly towards the center of the commutator, and it does not make any difference how small the commutator becomes through wear, the brushes will always point along one of the radii toward the center of the circle that here represents the outline of the commutator. For this reason, the brush holder is called a *radial* brush holder, and the brushes are radial brushes. The brushes are set on the quarter; that is to say, the distance from the center of one brush to the center of the other brush, along the surface of the commutator, is one quarter of the whole distance around the commutator.

**9.** If the brush holder is all right, it will, from its nature, put the brushes in the right place; but some types of brush holders, after they have been in use for a year or more and have been repaired several times, are not all right and require adjustment. In such cases, it is the custom to set the brushes by counting off the number of bars to be included between the centers and adding to this the width of about two mica bodies. There should always be included, between the centers of the brushes of such a motor, one quarter of the total number of bars in the commutator and a little over. A little over is added to allow not only for the thickness of one mica body that is not counted when the bars are counted, but also on account of the fact that a motor will run better when the brushes are a little too far apart than it will when they are a little too close together. The G. E. 1000 brushes,

then, must be set so that there are a little more than one quarter of 93 bars in between their centers; $\frac{1}{4}$ of 93 = $23\frac{1}{4}$ bars, and a little over. Now, when the brushes are in the motor, it is rather hard to count bars from their centers, because their centers are hard to see, so the brush inspectors have a practice of allowing for the thickness of the brush and then counting off between the inside edges, as shown at *K*, Fig. 14.

**10.** A brush holder gives the best results when it is set as near the commutator as it can without rubbing it. If it is too far away from the commutator, it will chatter badly and cause some sparking, which may not be seen, but which will shorten the life of the brush. As the commutator wears and is turned off, of course, it gets smaller and, therefore, farther away from the brush holder; in such a case, the only thing to do is to loosen up nuts *M*, *M*, Fig. 14, and slide the casting *H* down nearer to the commutator; nuts *M*, *M* must, of course, be tightened again, to secure the holder in its new position.

When a commutator begins to wear, its surface becomes curved, as shown in Fig. 15, and the new brush fails to touch anywhere but on its corners, which then have to carry all the current; sparking follows, and the life of the brush is short. The trouble can be partially remedied by turning the brush to fit as nearly as possible the shape of the commutator, but the best thing to do is to take the armature out and turn down the commutator in a lathe. A radial brush is supposed to point straight at the center of the commutator; whether it does or not can be told by the way the brush wears. If the wearing surface of the brush always remains at right angles to the faces of the brush, the brush holder is set right. If, however, the brush contact surface tends to wear on a bevel, it shows that the brush holder is out of line. Fig. 16 (*a*) shows the wear of a brush whose holder is in good order.

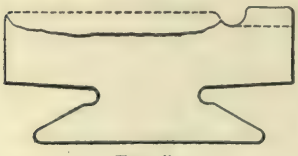


FIG. 15.

Fig. 16 (*b*) shows the beveled wear on a brush whose holder points towards some point below the center of the commutator, with the result that the two brushes include more than one-quarter of the bars between them.

When two brush holders point below the center, the longer they run the farther apart they get, and the more they spark. If, as in Fig. 16 (*c*), the bevel is in the other direction, it shows that the brush is pointing above the center of the commutator; in this case, the more the commutator wears down, the closer the brushes get together, and this causes sparking. In either case, there is a tendency to increase sparking, because the beveled wearing surfaces of Figs. 16 (*b*) and (*c*) are wider than the right-angled surface of Fig. 16 (*a*). The result is that the beveled surface can touch more bars at a time, and therefore short-circuit more coils than the straight surface can. In doing this, it may short-circuit a coil while it is yet in a comparatively active part of the field, so that the coil can generate current enough to cause serious sparking when the bar to which one end of the coil is attached leaves the brush.

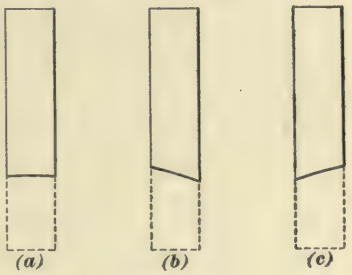


FIG. 16

It must also be borne in mind that as the commutator wears down, the bars get thinner so that a brush can touch more bars than it could when the commutator was new. This is why small old commutators, however smooth, do not run as well as large new ones.

**11.** Another point to look after in connection with the setting of brush holders, is to see that the holder does not rub the ear of the commutator or the head of the armature. The brush holder itself may be all right and still rub the bar ear or the head, because the armature may have too much end play. An armature shaft always has two collars

to limit the amount of end play to about $\frac{1}{8}$ inch, but after an armature has run several years, the wear on the collars allows it to play more from side to side.

When putting in a new brush holder, it is a good plan, before letting the car go, to run a bar down between the pinion and the gear case and force the armature over as far as it will go, to see if everything clears the brush holder. Raising the car wheels and running the armature is no reliable test, because so long as the truck is free, the magnetic field of the motor is able to keep the armature in the center, but if the car goes out on the road and runs into a curve at a good gait, the armature will be thrown to one side or the other as far as it will go, in spite of all the field can do. Then, besides, when the car is coasting along with the power off, there is no field and the armature is free to move sidewise as far as it pleases.

**12.** Another reason why the brush holder is liable to strike the bar ear or head, is due to the fact that the new wooden yoke *W*, Fig. 14, may be too thick or too thin. If the wooden yoke is fastened to the inner side of the commutator opening, as in the case of the G. E. 1000 motor, it will give trouble if it is too thin; but if, as is the case on some other motors in use, the wooden yoke is on the outer side of the opening, the yoke will give trouble if it is too thick. Still another source of the same trouble is to be found in the variations of castings made by different foundries. It is a well known fact that the dimensions of a casting are less than those of the pattern from which the casting is made. The casting shrinks, and the amount it shrinks is called the shrinkage for that particular metal. Now, in some cases, where a pattern is used a great deal, it is a great advantage to have the pattern itself made of metal. To do this, the pattern is first made of wood and a casting is then taken from it; this casting is then finished up to be used as a pattern from which the article to be used is taken. There are cases on record where the article to be used has, through error, been taken from the wooden pattern, in which case the article was too large,

because it had lost but one shrinkage where it should have lost two. Such a mistake on a brush-holder casting would be very apt to bring in troubles like the above, because the holder would hang out or in too far.

**13. Motor Bearings.**—The bearings, of which there are four on an up-to-date motor, are one of the most important parts of a motor. There are two axle bearings and two armature bearings. A great deal of study and experimenting has been done in late years to find out what is the best dimensions to give to bearings, with the result that liberal dimensions have been decided on. If the bearing is large in diameter and the rest of the shaft is built in proportion, there is very little danger of the shaft ever being bent, unless a bolt or a part of a broken gear-tooth gets in between the gear and the pinion while the car is in motion. On the G. E. 1000 motor, the length of the pinion and armature bearing is 8 inches and its diameter is 3 inches; the length of the commutator end bearing is 6 inches and its diameter is $2\frac{5}{8}$ inches. The axle bearings are of the same length, and are furnished in any of three sizes—$3\frac{3}{8}$ inches, $3\frac{3}{4}$ inches, and 4 inches—but, of course, can be babbitted and bored to any size up to 4 inches. Either oil or motor grease can be used in the armature bearings. If oil is used, the grease box must be packed with woolen waste; this waste not only prevents the oil from feeding too fast, but holds back grit and all other foreign substances liable to get into the box and either cut the axle or make it run hot. If grease is used, no waste is needed, but the grease should be kept in a covered barrel or can, so that no foreign matter can get into it.

**14.** In the axle boxes, motor grease is used. Motor grease has become an article so much in demand that any grease agent of good repute can furnish the article wanted, if he knows on what kind of a bearing it is to be used, and is paid a good price for a good article. There are two materials used about a motor that should not be economized on: one of these is babbitt, and the other is oil or grease. A good

article of either is worth keeping at any price, and experiments at random are apt to lead to regrets.

Motor grease is of two kinds: summer grease and winter grease. The summer grease, in northern climates, is apt to be too thick to flow freely in the cold, and will not, therefore, feed properly. On the other hand, winter grease will flow too freely in the hot weather and will go through a box about as fast as it can be put in. Boxes should be inspected regularly, and their packing, if there is any, renewed. Whenever the motors are brought in to be overhauled, the boxes should be thoroughly washed out with kerosene oil and repacked.

**15.** In spite of all the attention that may be given to a set of bearings, some of them will at some time run hot. To avoid this as far as possible, all bearings should be felt at intervals; if any of them seem to run abnormally warm, the car should be run into the house and the shop foreman told of it. If a bearing gets very hot, before it gives any violent symptoms of its condition, the odor of burning oil can be noticed, and it will smoke. In such a case, the best thing to do, if the hot box is on the armature, is to cut the motor out and run slowly to the house on the good motor. If a hot box on an armature bearing is not noticed in time, either of two things is liable to happen: (1) The armature shaft will cut into the bearing and not only ruin itself and the bearing, but will let the armature down on the pole pieces, and this, as a rule, results in injury to both the armature and the pole pieces. (2) The box may freeze; that is, the heat will expand the shaft so that it is too big for the bearing and the shaft will refuse to turn, nor is there power enough in the motor to make it turn. The wheels to which the armature is geared are locked, and when the car is moved, by means of another car, the locked wheels skid along without turning, and the only way to free them is to take down the gear case and draw off the pinion. If the pinion end of the armature shaft has not been much affected by the heat, it will not be hard to knock the pinion off, after its nut has been removed,

because the pinion seat *P*, Fig. 7, is tapered, as well as the bore of the pinion. The hard part is getting it started. If it is found impossible to force the pinion off, the only thing to do is to use a cold chisel and hammer to cut it off. The motor must, of course, be cut out and the car run in on the good motor.

**16.** If an axle bearing runs hot, it can very often be relieved, to some extent, by loosening the axle cap bolts and putting in some fresh oil or grease, but the car should not be allowed to go out on another trip until the box has been inspected, for if the axle has begun to cut, it may do more damage than the profits of several trips amount to. In some cases, an axle will begin to cut and get rough, and a timely use of oil or grease will cause it to find a new seat and run smooth again. In most cases, however, it keeps on cutting until it is necessary not only to remove the brasses, but to take the axle out and draw-file it. There are cases on record where a car has come into the house for one reason or another, with nothing to show that it ever had any axle brasses, save a great accumulation of brass dust in the gear case, on the gear, and around the rear end of the frame in general. The brasses had been ground to powder, and the axle was running in the iron axle caps. It is a mystery how an axle could go through such an experience without giving rise to such violent demonstrations as would call attention to its condition, but it is a fact well known. A newly equipped car should not be put into service until its bearings have been well tried. A fair trial consists in running the car for a mile or more at high speed and with the tension taken off the bearing capscrews, to give the bearings a chance to find a good seat. The caps are then secured and the car given another spin up the road. If none of the bearings show a tendency to heat, it is fair to suppose that they are in good condition; but it is an excellent plan, where practicable, to put a newly equipped car on a run that brings it past the shop, so that any failing can be found out before it does much harm. To give an idea of how much it means to have

good bearings on a car, it can be stated as a fact that a newly equipped car, in good condition, takes from 20 to 30 per cent. more current to run it than that same car will take after it has been on the road for several days. Some idea can be had, then, of how much power is lost when the car has hot bearings gripping the axle like a brake.

**17. Gearing.**—Fig. 17 shows how a street-car motor armature is connected to the car axle; in this figure, *P* is the small gear, called a *pinion*, forced on to the tapered end of

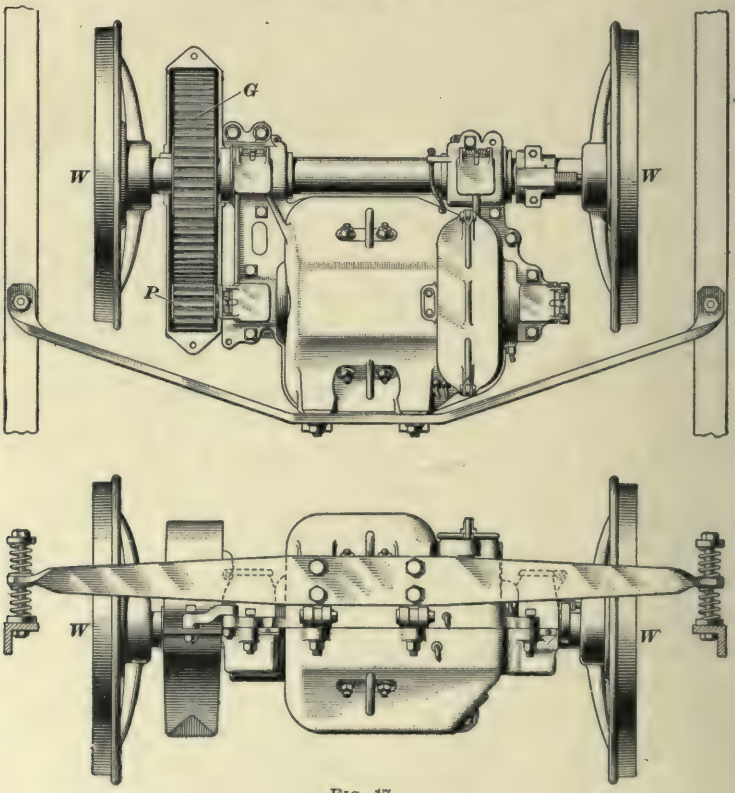



FIG. 17.

the armature shaft and secured by means of a nut and spring washer; *G* is the big gear, which is made in two parts, as

shown in Fig. 18, so that a gear can be put on or taken off without pressing one of the car wheels $W$ off. In one of the halves, a keyway $k$, Fig. 18, is cut to take a key that is set in the axle; this key is intended to keep the gear from turning around free of the axle, and all fitting having anything to do with this key should be well done. The gear is supposed to turn with the axle. The two halves of the motor frame are clearly shown, and the springs at the side, resting on the truck, are intended to cushion the blows struck by the motor when the car is running over rough track. The gear and pinion must necessarily turn in opposite directions. As soon as the current goes into the motor, the armature turns, say, in the direction of the hands of a watch; as the teeth of the pinion mesh with those of the gear, the car wheels turn in a direction opposite to that of the hands of a watch. If the pinion has, say, 16 teeth and the gear 65 teeth, the motor armature must turn $\frac{65}{16} = 4\frac{1}{16} = 4.06$ times, in order to make the car wheel turn once. In this case, the gear reduction is said to be 4.06 to 1.

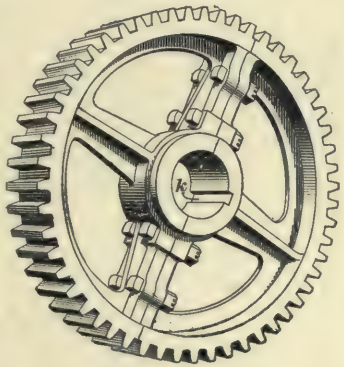


FIG. 18.

If the pinion had 13 teeth and the gear 68 teeth, the armature would have to turn $\frac{68}{13} = 5\frac{3}{13} = 5.23$ times, to make the car wheel turn once, and the gear reduction would be 5.23 to 1. If the gear and pinion had the same number of teeth, which in this case would not be possible unless the distance between the centers of the shaft and axle were changed, there would be no reduction at all. From the above can be drawn the conclusion, then, that the larger the pinion is, the smaller is the gear reduction, and vice versa; also, the larger the gear is, the greater is the reduction, and vice versa. In other words, if a car is equipped with a gear and pinion of a certain size, the car can be made to go faster by increasing the

size of the pinion and decreasing the size of the gear by the same number of teeth. It is necessary that the total number of teeth be kept the same, because the distance between the centers of the axle and shaft is fixed, and so is the design of the tooth on both gears. The result of leaving out a tooth would be to decrease the diameter of one gear, so that the two gears would be too far apart to mesh properly. The effect of adding a tooth to the total would be to bring the gears so close together that they would not mesh at all.

**18. Effect of Changing the Gear Reduction.** There are several reasons why the gear reduction is sometimes changed, and among these reasons are the following: The car may be too slow, or it may be too fast and use too much current. If a car is too slow, the way to make it faster is to use a larger pinion and a smaller gear; but, before making any great change in this direction, it is well to talk it over with some one that knows all about the motor in question and can also tell about how much more current the car will take after the proposed change in the gears is made. It must be borne in mind that it takes a certain amount of current to run a car at a certain speed, and to run it at a greater speed will require an increase in this power, as the voltage on the trolley line is kept about the same—500 volts—under all conditions, and the increase of power furnished to the car is in the form of an increased current, which the wire in the motor may not be able to stand. Also, the effect of making the gear reduction less is to also make the car's starting power less, because the two gears on a car form simply a combination of levers, by means of which the armature turns the car wheel.

The pinion pinches the gear around much the same as a man does when he pinches the car along by using a crowbar between the wheel and the rail; and shortening the length of the crowbar, thereby giving the man less purchase, is the same in effect as shortening the radius of the big gear, thereby giving the pinion a shorter lever to work with. On the other hand, if the car is too fast or takes too much current,

it is always safe to use a larger gear and a smaller pinion, but there is one point to bear in mind when increasing the size of the gear, and that is, that a much larger gear will call for a larger gear case, and, in providing such a gear case, it must be borne in mind that, in some places on the road, the paving may be 2 or 3 inches above the level of the rail, thus limiting the size of the gear case that can be used.

**19.** In cases where it is necessary to use a gear that is too large to admit of the use of a gear case, the gear case can be discarded and a rawhide pinion used. Rawhide pinions cost more than steel pinions, but they require no grease, oil, or gear case, and even then make less noise than steel pinions running in gear grease. Where rawhide pinions are used, the wear on the gears is less and they last much longer, which is an item very much in their favor, because gears are more expensive to buy and more expensive to change than pinions.

**20.** Increasing the size of the pinion and decreasing the size of the gear was seen to make the starting power of the car less and its full speed greater. Decreasing the size of the pinion and increasing the size of the gear gives the car greater starting power, but somewhat lessens its maximum speed. It increases the starting power, because it increases the length of the lever that the armature uses for turning the car wheel, as can be seen by a consideration of Figs. 19 and 20. In Fig. 19 *c d* is a lever working around center *O*, and *a b* is a lever working around center *O'*. Attached to one rope is weight *W*, which tries to turn lever *a b* counter-clockwise; attached to a second rope is weight *w*, which tries to turn lever *c d* also counter-clockwise. We will suppose that the lengths of the levers and the weights

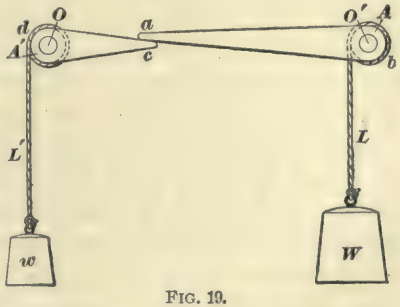



FIG. 19.

of $W$ and $w$ are such that the levers, when interfered, as shown in Fig. 19, just balance each other in the effort to press, the one up and the other down. It can be readily seen that the amount of weight $W$, which one could lift by winding rope $L$ up on arbor $A$, by means of lever $a\,b$, would depend on the length of lever $a\,b$, just as the weight that a man can move with a pry depends on the length of the pry.

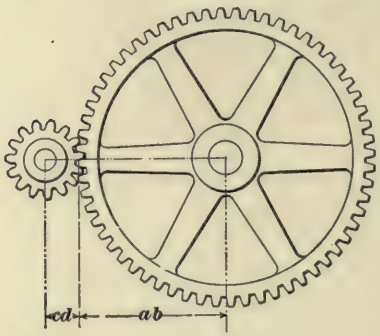


FIG. 20.

If lever $a\,b$ is very long, a man lifting a few pounds at $a$ with his hand, can move a weight of several tons at $W$; but it must be borne in mind that he would have to move the end of the lever through a great distance compared to the distance through which the weight $W$ is moved. Whatever is gained in the amount of weight lifted at $W$, is lost in distance through which the weight is moved for a given range of movement of the lever $a\,b$. Now, suppose the man's efforts to be replaced by those of lever $c\,d$, which is actuated by the efforts of weight $w$, to unwind rope $L'$ from arbor $A'$. The longer lever $a\,b$ is and the shorter lever $c\,d$, the more weight at $W$ will a given weight at $w$ be able to balance; and also the less weight will it take at $w$ to start in motion a given weight at $W$. Now, the weight at $w$ depends upon the turning or twisting power of the armature, and the weight at $W$ depends on the resistance that the car offers to being moved. The length of lever $a\,b$ stands for the distance between the center of the car axle and the center of one of the teeth of the gear, as shown in Fig. 20; and the length of lever $c\,d$ stands for the distance from the center of the armature shaft to the center of one of the pinion teeth. So it can be seen that the greater the distance $a\,b$, Fig. 20, and the less the distance $c\,d$, the more starting power will a car have for a current of given value through the motors.

**21.** A car's starting current is practically understood to mean the current that the motors take when the rheostat or controller is on the first notch, and the value of this current is limited only by the resistance of the starting coil. Of course, there are conditions under which a car fails to start on the first notch, but on a level and with a load not exceeding that which the motors are intended to pull, the car should start on the first notch; if it does not, the symptoms are that something is wrong either with the motors or with the starting coil. The motors may be too small for the work or the starting-coil resistance may be too great.

**22. Change in Gear Reduction.**—An increase in the gear reduction will cause a proportionate increase in the starting power of a car, but will not bring about a proportionate decrease in the maximum speed. That is to say, if, at first, the gears have four times as many teeth in them as the pinions, making a gear reduction of 4 to 1, and the gears and pinions are changed, so that the gears have five times as many teeth in them as the pinions have, making a gear reduction of 5 to 1, and making an increase in the gear reduction of 25 per cent., the starting power of the car will be made 25 per cent. greater, but the speed of the car will not be reduced as much as 25 per cent. The starting power is increased 25 per cent., because, in both cases, the starting current is the same, its value being limited only by the resistance of the starting coils that remain the same, and the change in the starting power is due simply to improvement in the mechanical facilities for handling the twisting effect caused by the given current in the armature coils. The mechanical condition, that is, the lengths of the levers *a b* and *c d*, have been improved 25 per cent.; therefore, the starting power has been improved also. The full speed is not reduced 25 per cent. on account of the 25-per-cent. change in the gearing, because, for a given weight of car, the armature runs faster than it did before—how much faster, depends on several things, a discussion of which would be beyond the scope of this work.

Every motorman knows that his car will run faster with a very light load than it will with a very heavy one, because the additional weight, due to a heavy load, gives the armature more work to do turning the gear around by means of the pinion. In other words, when the load is light, the armature can turn faster because it has less resistance to force its pinion around against. Now this resistance can be made less in two other ways, besides taking weight off the car. One way is to make the car wheels smaller: put in 30-inch wheels in place of 33-inch wheels. The other way is to make the pinion smaller and the gear larger, thereby giving the pinion better leverage, so that it can turn the gear with more ease. Changing the gearing on a street-car motor is a different proposition from changing the gearing on a lathe or any other device, which is run from a countershaft or engine having constant speed. Take an engine pulley, for instance: it does not matter what is belted to that engine, provided it is not overloaded, nor how much the gears or pulleys on devices run from the engine are changed, the speed of the engine keeps about the same, because the governor on the engine controls the speed. Further, it is a well known fact that if the engine pulley is belted to another pulley of the same size, the two pulleys will run at practically the same speed. What little difference that does exist is due to a slight slipping of the belt. If the engine pulley is belted to a pulley half its size, the smaller pulley will turn twice as fast as the engine pulley, and a pulley twice the size of that on the engine would run half as fast as the engine pulley, and so on.

**23.** The armature of a street-car motor does not run at a constant speed. Its speed depends on how much work it has to do. Let us take, as an example, a car weighing, complete, 14,000 pounds, and assume that it is running at full speed on a level stretch of track, and that the line voltage is kept exactly at 500. If the motors are alike, and are geared the same, with both sets of wheels exactly the same size, the two armatures will turn at the same speed, and each will take

the same amount of current. One armature alone, then, can be considered. Suppose now that the car is run in and its gears and pinions changed so as to increase the gear reduction 25 per cent. If it were a fact that the armatures now run at the same speed as they did before the gears were changed, it would also be a fact that the car runs 25 per cent. slower than it formerly did; but the fact is, that, since the change in the gears has been of a nature to make it easier for the armatures to turn, both of them turn faster than they did before. The car does not run faster than formerly, because the effect of changing the gears to a slower combination more than balances the speeding up of the two armatures; but the car runs faster than it would run were the speed of the armature the same as it was before the change of gears. The net result is to cut down the speed, but not 25 per cent.

**24. How to Put On a Gear.**—To put on a gear in good shape is more of a job than some people think it is. It will be assumed that all the teeth in the gear are the same size, and that the two halves are mates; that is, that they have been bored together and that the hole is in the center. The first thing to do is to inspect the gear, to see that it is the size and bore wanted, and that it has no cracks visible to the naked eye, and that its teeth have not been hammered on the end, making a ridge that is apt to spring the armature shaft as soon as it is run. If there are any ridges, they must be chipped off and dressed with a file. The next step is to lay the gear down and take the bolts out. If any one sees you trying to take out the bolts with the gear standing up, he will know that you have never tried it before; use an **S** wrench or a socket wrench for removing the nuts—never a monkey wrench, if you can help it. When the two halves of the gear come apart, sometimes, though not always, four little strips of sheet iron called *shims* will fall out. It may come handy to use these, and it may not; some men use them and others do not. The gears are cut with these strips in between the halves, and the result

is that each half of the gear is a little bit less than one-half of a circle.

The idea of the *liners* or *shims* is this: If the axle on which the gear is to go is the least bit too small, the gear will still pull tight on the axle if the shims are left out. Before putting the gear on the axle, the key should be fit snugly into the axle keyway, so that the key, if it is struck with a hammer, will give off a sound the same as if the axle were struck. When this is the case, one may be certain that the key is in solid. Before putting in the key, take a file and smooth all the burr off its corners and try it in both the axle and gear keyways, being certain, of course, that there is no burr in either keyway. If all three are in good shape, the key is put in place and one-half of the gear put on. If the gear fits as it should, it will not go on without a little pounding; to do this, lay a block of wood on top of the gear and hit the block of wood with a sledge. If, under this treatment, the gear fails to go on, it is bored too small or the axle may be a trifle large; in either case, the custom is to take the gear off and bore it to fit the axle. But, where it is possible, it is a much better plan, if the axle is too large and the gear is bored right, to turn down the axle to the right size, because both of them are then kept to standard; but if the gear is bored out, the next gear that is put on that axle will have to be bored out too.

If the gear fits the axle exactly, without any forcing, it is a good plan to put a piece of thin paper in between them and force the gear on over this. The gear is then much less apt to get loose. In some cases the gear goes on so loosely that it is necessary to put in a liner of thin iron or emery cloth. The loose fit may be due to the fact that the axle is old and the gear seat a little worn. A pair of calipers will soon tell where the trouble is. If the fault is found to be in the gear, the fact should be made known to the company's buying agent, so that he can tell the man that sold the gears, and thereby avoid more of the same trouble in the future. If a gear is too small for the axle, it is an easy matter to bore it out, but if it is too large for the axle, the only thing to do is

to shim it up, for the gear cannot be bored smaller, nor can the axle be turned any larger. It is even the custom to put gears of 4-inch bore on to $3\frac{5}{8}$-inch axles; but in such cases the lining must be done with great care and the key must be made deeper to allow for the depth taken up by the liner. When a liner or shim gets to be $\frac{3}{16}$ inch thick, as it is in this case, it is called a *bushing*, and the way to go about making such a bushing is as follows: Make a wrought-iron ring of the width of the gear and of such a thickness that its outside can be finished to fit the bore of the gear (4 inches) and its inside to fit the $3\frac{5}{8}$-inch axle. The ring is then put in the lathe chuck and its inside finished so that it will drive true on a mandrel to get its outside finish. There is then sawed out of the ring a piece the width of the key, so the key can pass through it up into the key seat in the gear. The ring can now be split, so it can be put on the axle, and the job is done.

A gear bushed in this way will give no trouble. If the upper half, that is, the half with the key seat in it, is a good fit, the lower half is very apt to be. The upper is much the harder of the two to do a good job on, because it has the key to fit in it. As soon as the upper half is in place, the axle is turned and the lower half put on, and the bolts put in. On all modern gears, there are lugs cast to keep the bolt heads from turning when the nuts are tightened up; by means of these lugs, one can tell which way to run the bolts through. Lock washers are always put under the nuts so the nuts cannot come loose, fall off, get in between the gear and pinion, and bend the armature shaft or break the motor frame. In tightening up the bolts in a gear, the ones nearest the axle should be tightened up first. When a gear is on right, the top of every tooth is the same distance from the axle, and the face of the hub squares up with the axle. Of course it is not necessary to split hairs in applying these tests, but the nearer right the gear is, the longer will it run without giving any trouble.

**25. Gear Troubles.**—If a gear gives out a clicking or knocking noise every time the car wheel turns once, it may be

due to any one of several causes. The gear may be loose on the axle; the gear may be open on one side where the two halves come together; the gear may have in it one tooth that is bigger than any of the other teeth. The last is very often the case, and is the fault of the man or of the machine that cuts the gears. A big tooth in a gear is readily detected by turning the gear over, because the big tooth shows wear where it knocks.

**26.** In case of a loose gear, the car should be called in at once, because the gear will not only hurt itself, but will ruin the key seat in the axle so that a new seat will have to be cut before another gear can be put on. If the gear clicks twice every time the car wheel turns once, it means that the two halves of the gear have not been pulled together, and that the gear is therefore open on both sides, giving the same effect as two big teeth opposite each other would give.

**27.** If a gear gives forth a periodical grinding noise, it indicates that the gear is not round, that it has been sprung in drawing the two halves together, that it has been set on the axle lopsided so that it runs out of true, or that the car axle is slightly sprung. If the axle is sprung, the whole motor frame will be seen or can be felt to move, as the car wheel goes round each time. A rapid clicking noise means that there is something the matter with the pinion. It may be a big tooth or the armature shaft may be sprung. To find out, take off the pinion, spin the armature and watch the end of the shaft as it goes around. If it does not wabble, put on a pinion that is known to be perfect and spin the armature again; if the click disappears, it fixes the fault on the pinion that was taken off. It is a well known fact that the teeth on a gear tend to wear wedge-shaped. This is due to the fact that as the gear and axle bearing wears and gets play in it, the teeth of the gear cease to be parallel to the pinion teeth, so that both wear on one end more than on the other end. The gear is fixed to the axle and cannot move,

but as the axle bearings wear, the motor can throw over more or less and the armature and the pinion throw with it. To avoid this wedge-shaped wear of the teeth, the gear end axle bearings must be kept in good order.

---

### GENERAL ELECTRIC 52 MOTOR.

**28.** The G. E. 52 motor is a lighter motor than the G. E. 1000 motor, and is made to do lighter work. The G. E. 1000 motor weighs 1,900 pounds, and has a rated input of 35 horsepower; the G. E. 52 motor weighs but 1,460 pounds, and has a rated input of 27 horsepower. Weights do not include the gear and gear case.

**29. Rating of a Motor.**—Before taking up the parts of a G. E. 52 motor, it might be well to consider briefly the grounds on which a motor gets its rating. As a rule, when a motor is referred to as being of a certain horsepower, the rating refers to the electrical horsepower that it can safely absorb, and not to the mechanical horsepower that the motor can give out. A 20-horsepower motor, then, is one that can absorb safely 20 horsepower electrically. A 27-horsepower motor is one that can safely absorb 27 electrical horsepower. Now, to get at the bottom of the thing in an intelligent manner, we must find out what is meant by horsepower.

**30. Horsepower.**—A horsepower is a unit that names the rate at which work is done. If a man has 1,000 pounds of brick to place on top of a structure that is 50 feet high, it does not make any difference, as far as the amount of work done is concerned, whether the man takes those bricks up in 2 hours or in 2 years; the work done is the same in both cases. The true meaning of the word *work* is conveyed by the idea of lifting a weight through a certain height. If a man does the lifting, the work is done by the man; if a machine does the lifting, the work is done by the machine. In either case, the amount of work done is equal to the weight in pounds lifted, multiplied by the number of feet

through which it is lifted against the attraction of the earth. Now, feet multiplied by pounds give a product expressed in units called *foot-pounds*, and 1 foot × 1 pound = 1 foot-pound, the mechanical unit of work. A foot-pound of work can be done by lifting 1 pound through 1 foot, or $\frac{1}{2}$ pound through 2 feet, or 2 pounds through $\frac{1}{2}$ foot; it does not matter what number of pounds or fraction of a pound, or what number of feet or fraction of a foot there is, so long as their product is 1, the work done is 1 foot-pound.

In the example above, taking 1,000 pounds of brick to the top of a 50-foot building, the work done is 1,000 pounds × 50 feet = 50,000 foot-pounds of work, but the work done would be the same were 2,000 pounds of brick carried to the top of a 25-foot building. If 33,000 pounds of brick were taken to the top of a 1-foot structure, there would be 33,000 foot-pounds of work done, and this would be so whether the bricks were taken up one at a time or all at once, or whether they were taken up in 5 hours or in 5 years. If, however, the 33,000 pounds of brick were taken up 1 foot in 1 minute, this would be doing the work at the rate of 1 horsepower; if it took 2 minutes to take them up, this would be at the rate of 16,500 pounds per minute, or $\frac{1}{2}$ horsepower, because the meaning of the term *1 horsepower* is that work is done at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Any man could take the bricks up in course of time, but no man could take up the 33,000 pounds in one minute. It ought to be easy now to see that there is a great deal of difference between doing a certain amount of work and doing that work at a certain rate. The unit of work is the foot-pound; the unit of rate of doing work is the horsepower.

**31. Electrical and Mechanical Units of Power.**—Let us now consider the connection between the mechanical and electrical units of power. In an electrical circuit there are three elements to deal with: *voltage*, *current*, and *resistance*. The unit of quantity of electricity is the *coulomb*. When 60 coulombs of electricity pass any given point in the circuit in 1 minute, a current of 1 ampere is said to be flowing in that

circuit; so the ampere itself can be seen to be a rate of flow of current. The current in amperes is the quantity of electricity that is moved per second in an electrical circuit, and it corresponds to the bricks moved per second in the above example. In other words, the number of amperes is equal to the flow in coulombs per second. The voltage corresponds to the distance through which the weight is lifted, and the resistance to the pull of the earth, for it is this pull against which the weight is lifted.

To get the amount of work done per second in an electrical circuit, the voltage is multiplied by the current; that is, the volts by the amperes. When 1 volt is multiplied by 1 ampere, the result is a unit, called the *watt*, and there are 746 watts to the horsepower, so that the horsepower that is being put into a motor can be gotten at any time by measuring the voltage with a voltmeter and the current with an ammeter, multiplying the two readings together and dividing by 746. Now watts and foot-pounds per second are units of the same kind, but they vary in degree, just as quarts and pints are units of the same kind that vary in degree. It takes 550 foot-pounds per second to make a horsepower, and it takes 746 watts to make a horsepower; 1 foot-pound per second is one-third again as large as a watt, but one can be converted into the other. To convert foot-pounds per second into watts, multiply the foot-pounds per second by 1.36; to convert watts into foot-pounds per second, multiply the watts by .737.

**32. Losses in Motors.**—When the current flowing through a motor is multiplied by the volts at its terminals, the result is a certain number of watts, which tell how much work is going into that motor every second, and this is called the *input* of the motor. The input is used up in two or more ways. One part of the input is wasted in turning the armature around against the friction of the bearings and brushes. Another part of the input is spent usefully in urging the car along. A third part is spent in heating up the iron and copper parts on the motor. When the current passes through the copper wire that composes the winding,

it heats it and it is on the degree of this heating that the rating of an up-to-date street-car motor is based. We cannot admit that this basis is the most common-sense one that could be selected, because the average street-railway superintendent is more interested in what size motor will pull a given car over a given track at a given number of miles per hour, than he is in how hot the motors will get in doing the work laid out for them. In other words, the amount of heat that a motor will develop under certain conditions does not, to most men, throw much light on the question of whether it will do the work or not.

**33. Rating of G. E. 52 Motor.**—To quote the text as found in the "Street Railway Journal": "The G. E. 52 motor has an output of 27 horsepower, rated according to our standard basis, i. e., a maximum rise of 75° centigrade (centigrade is a name applied to a thermometer whose freezing point is 0 and whose boiling point is 100) in the temperature of the windings after a run of 1 hour at rated load (27 H. P.), the temperature of the surrounding air not exceeding 25° centigrade." All of this means that if the G. E. 52 motor is run for 1 hour at a load of 40 amperes at 500 volts, in a room whose temperature is 23° C. or less, at the end of the run, the motor fields and armatures will be no more than 75° C. hotter than the air in the room. We might quote further from the General Electric Company's bulletin, which says: "The G. E. 52 motor is intended only for ordinary street-railway work similar to that handled by the G. E. 800 motor, and is not recommended for the heavier service to which the G. E. 1000 motor is adapted. The motor has been designed similarly to the G. E. 1000 motor to accommodate electric brakes, when so desired; but as some additional capacity is required where electric brakes are used, this motor is not recommended for such service, excepting where the duty required of it will be light."

**34. Motor Frame.**—The frame is steel, and is cast in two bowl-shaped pieces *A*, *A*, Fig. 21, which are hinged

together as shown. This figure shows the lower half swung down, with the armature in the upper half. As on the G. E.

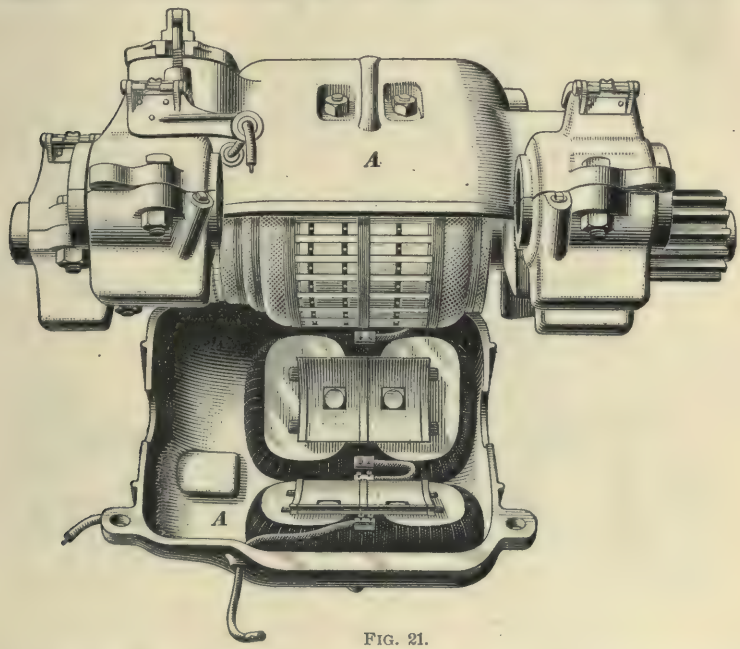



FIG. 21.

1000, the two halves close together so as to make the motor dust-proof and waterproof. Fig. 22 shows the motor closed,

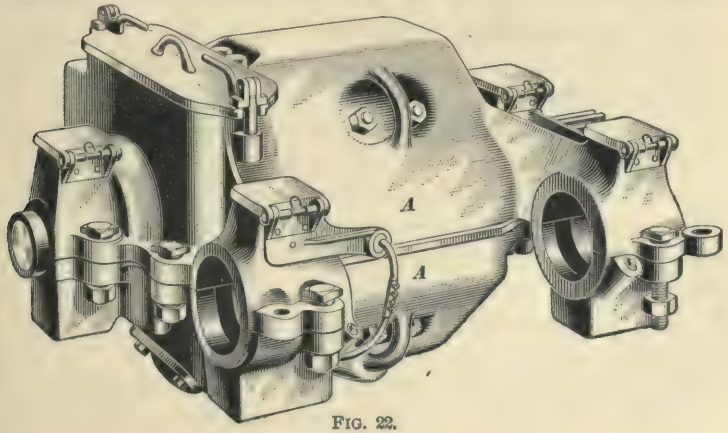



FIG. 22.

and Fig. 23 shows the armature bearing caps detached and the armature swung down with the lower half. The bottom

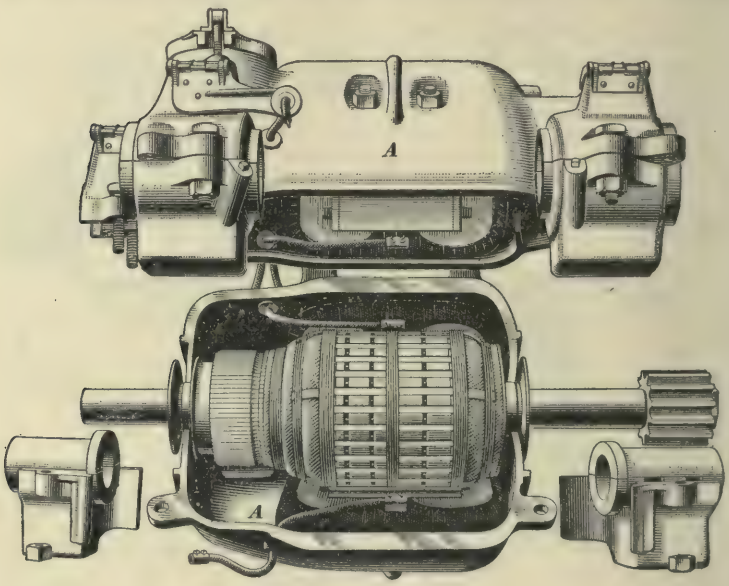



FIG. 23.

shell is provided with a handhole through which the motor can be inspected and cleaned.

**35. Pole Pieces.**—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place and the laminations not only do away with a great deal of heat in the pole piece, but, from the way in which they are built up, they produce a magnetic field, which does away with a great deal of sparking at the brushes. The pole pieces are made up of iron plates shaped something like the full-line part of Fig. 24 (*b*). The pole pieces are built up of these plates, every other one of which is turned end for end. The result of this manner of construction is shown in Fig. 24 (*a*) where, in the center part of the pole piece, the plates are close together, but on the horns, only half of the plates come out on each side. This

construction does away with heating, because most of the heating that takes place in a pole piece is due to currents generated in it, and these currents are heaviest in the horns where the most work is done. Where the pole piece is solid, the currents have a free path of very low resistance, and grow to be large. With the open construction on the horns,

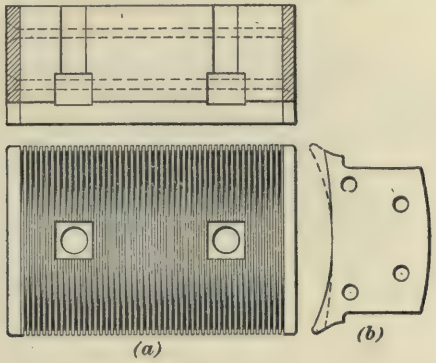



FIG. 24.

the air gaps in between each pair of plates put a high resistance in the way of these currents, called *eddy currents*, because they whirl around in the iron like an eddy in the water, and they cannot amount to much. This plate construction, to a great degree, does away with sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces what is called a *shaded field* or *fringe*. This means that the pole-piece horns are so made that the lines of force are thrown in such a way that they get thinner and thinner at the proper rate and in the right place.

It can be stated as a fact, that on one side of a brush, the current in any given armature coil is in one direction, and, on the opposite side of the brush, the direction of the current in the coil is reversed. This is because, on one side of the brush, the coil cuts the lines of force going down, and, on the other side, it cuts them as it goes up. While the coil is under the brush, it is short-circuited, and at some instant generates no current at all, for it cuts no lines of force; but

there is a current in it just the same, and for this reason, just before the coil reaches the brush, it is carrying just as much current as any other coil. Since every coil carrying a current has self-induction, it is not possible to stop this current in one instant; so even after the coil is short-circuited, the current keeps on running round and round in it, and if the coil leaves the brush while this induced current is flowing, it will drag an arc after it. The idea of the shaded field is that the proper number of lines of force are so directed that the coil begins to cut them before it leaves the brush. The result of the cutting of these lines of force is to exactly neutralize the induced current in the coil, so that the coil leaves the brush with no current, hence with no sparking.

**36. Field Coils.**—The field coils, like all field coils on recent types of G. E. motor, are wound with asbestos-covered wire, which in the process of winding goes through a special course of treatment called *mummifying*. It may be said for the relief of those who read this, that few repair shops, when winding G. E. 52 fields, care to stick to this special treatment, as the motor seems to do well when the same number of turns of double cotton-covered wire of the right size is wound on dry.

**37. Armature.**—The G. E. 52 armature core has 29 slots in it, and one side of 6 coils goes into each slot, making 87 coils in all. The commutator has 87 bars. The coils are

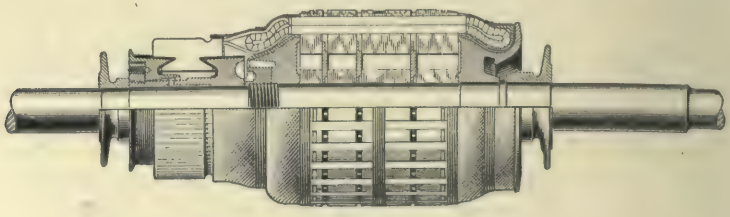


FIG. 25.

bunched 3 in a slot, because such a construction not only cheapens the cost of making an armature, but it makes the armature easier to repair. Fig. 25 is a half section of a

G. E. 52 armature, and shows clearly the arrangement of the parts. This armature is generally wound with 4 turns per coil of No. 10 B. & S., making a total of 348 turns.

**38. Brush Holder.**—Fig. 26 shows the G. E. 52 brush holder, which is about the same as that of the G. E. 1000,

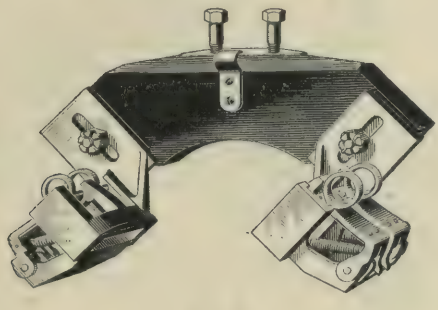


FIG. 26.

and it goes through the same course of treatment in its manufacture. Each holder takes two brushes $2\frac{1}{4}$ in. $\times$ $1\frac{1}{4}$ in. $\times \frac{1}{2}$ in., and they are of the radial type.

**39. Gears.**—The standard gear for the G. E. 52 motor has 67 teeth and the pinion 14 teeth, making a gear

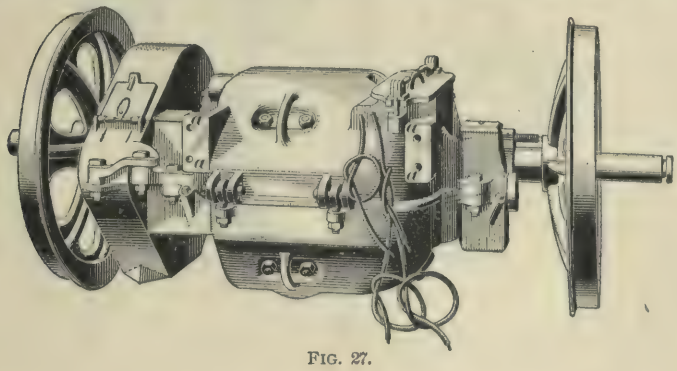


FIG. 27.

reduction of $\frac{67}{14} = 4.78$ to 1. Fig. 27 shows the G. E. 52 motor mounted on the axle. The holes *a*, *a* receive

the bolts for attaching the suspension bar to the motor. This bar rests on springs supported at each side by the truck, and thus holds up the motor (see Fig. 17). The figure also shows very plainly how the fields and armature leads are brought out.

---

### GENERAL ELECTRIC 800 MOTOR.

**40.** The G. E. 800 motor was about the first motor put on the market by the General Electric Company; that is, the first one put out after the Thomson-Houston and Edison General Electric companies united, and it is a motor that is doing well today in many places where it is not abused. The G. E. 800 motor is rated at 27 horsepower; its full-load current, then, is 40 amperes.

**41. Frame.**—The frame is of steel, cast in two halves bolted on one side and hinged on the other. Unlike the 1000 motor, its general shape is that of a cube. To open up the motor and take out a field or armature, it is necessary,

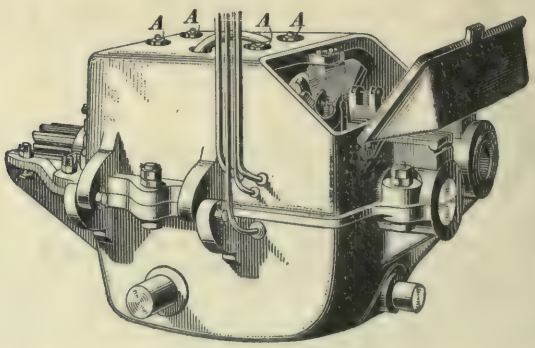



FIG. 28.

in most cases, to roll the truck out from under the car; but most street-railway men do not now look upon this as a bad feature, because most of them think that it is best for the car and also for good inspection. Fig. 28 shows the motor

closed and Fig. 29 shows it open for taking out an armature or a top field. The motor cannot be opened from below

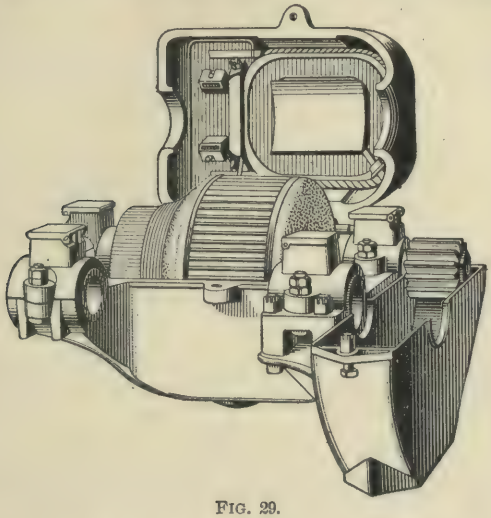


FIG. 29.

because the frame is hung from the lower half, and, since the armature bearing caps are bolted to the lower shell, the armature cannot be left in the upper shell.

**42. Field Coils.**—There are two fields, one of which goes in the top and the other in the bottom, as shown in Fig. 29. As the pole pieces on which the field coils go are cast on the frame itself, they cannot be flanged, because the coils could not then be put on over them. Since the pole pieces are not flanged, they cannot hold the coils in place; so the coils are wound in shells that are secured by means of bolts *A*, *A*, *A*, *A*, Fig. 28, passing through removable flanges. There are several kinds of fields provided for the motor, to meet different conditions of service. One kind that has been adopted by several large roads consists of 190 turns of No. 6 B. & S. gauge, double cotton-covered, round copper wire.

**43. Armature.**—One popular style of G. E. 800 armature has 105 slots in it, and it is wound with 105 coils having

3 turns each of No. 10 wire. Some coils have 4 and 6 turns each. It is very similar in appearance to the G. E. 1000 armature.

**44. Gears.**—The standard gear reduction is 4.78 to 1, or 14 teeth in the pinion and 67 teeth in the gear.

**45. Bearings.**—The axle bearings can be babbitted up to $3\frac{3}{4}$ inches diameter. The armature bearings are also babbitted; the dimensions of the commutator end are $2\frac{1}{2}$ in. $\times$ $4\frac{1}{2}$ in. Those of the pinion end, which, of course, have the greater strain of the two, are $2\frac{1}{2}$ in. $\times$ 6 in.

**46. Shunt.**—The field is shunted with a 2-ohm resistance coil that relieves it somewhat.

**47. Speed.**—Two G. E. motors under full load will propel a car that calls for that load about 10 miles per hour on a level. Ordinarily, the motors do not take full load, and therefore run much faster than this.

# CAR EQUIPMENT.

(PART 7.)

## GENERAL ELECTRIC EQUIPMENT.

### GENERAL ELECTRIC CONTROLLERS.

**1. Classification.**—Inasmuch as the General Electric Company makes the best controller manufactured, and as there are as many of them in use as there are of all other makes combined, it will not be out of place to consider these controllers more fully than any of the others. There are four types of G. E. controller; they are designated as types K, L, B, and R. It is said that these type letters have no other meaning than that they show the type to which the controller belongs, but it is a fact worth remembering, that although this may be true of type K, the other three type letters happen to have a meaning. The K, K2, K10, K11, . . . are used on trolley cars; the L types are used a great deal on elevated railroads or "L" work; the B types operate electric brakes; R is the first letter of the word rheostat and the type R controllers are purely rheostatic. The General Electric Company, in fact, assign to the type letters the following meanings: K refers to those controllers whose drums, in going from series to parallel, shunt and finally short-circuit one of the motors; L refers to those motors



For notice of the copyright, see page immediately following the title page.

whose drums, in going from series to parallel, drop both motors and pick them up again with a resistance in series—the main circuit is entirely opened when the controller leaves the last series notch; B refers to those controllers that are fitted to control an electric brake; R refers to controllers that control one or more motors by means of a resistance that is cut out, part at a time, as the controller handle goes from notch to notch.

**2. Uses of Controllers.**—Any of the G. E. controllers may be used to control one motor or two or more motors connected permanently in series or in multiple; but the type K is not recommended for such work, because, where straight rheostatic control is used, several resistance notches are required in order that the car may start smoothly, and the type K can operate only a two-part resistance. By a two-part resistance is meant a resistance coil that is divided into two sections—one section is cut out on the second notch and the remaining section on the third notch. Fig. 1 shows a one, two, three, and four part resistance coil. Some of the controllers are intended to be used on motors that employ shunts and some are not; those designed for use with a shunt have two more fingers than they would have were no shunt used. A controller designed for use with a shunt can be used on motors that employ no shunt, but controllers that have no shunt fingers cannot be safely used with motors requiring a shunt. In the second case, no shunt can be used, unless it is cut in permanently, because there are no fingers to cut it in, and if the shunt is not used, the motors run all the time on full field, which may be more than the fields can stand, since they

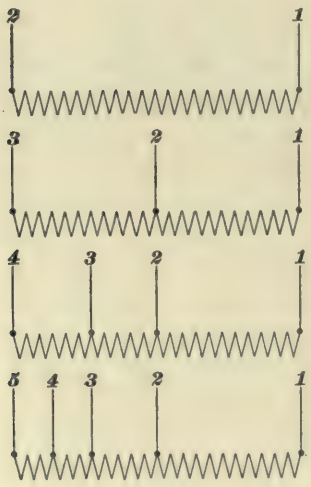


FIG. 1.

heat more when they have no shunt to relieve them of some of the current. The two G. E. controllers that will be taken up in this section are the K2 and the K11, because there seems to be more of these in use than any other type.

---

### THE K2 CONTROLLER.

**3. General Description.**—The K2 controller is used on motors of 35 horsepower or under, and has nine notches. There are more positions than this, but only nine of them are marked, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the drum will not hang between notches and cause burning inside the controller. Fig. 2 shows the K2 controller with the door closed as it appears on the end of a car; Fig. 3 shows the door opened so that the inside parts may be seen.

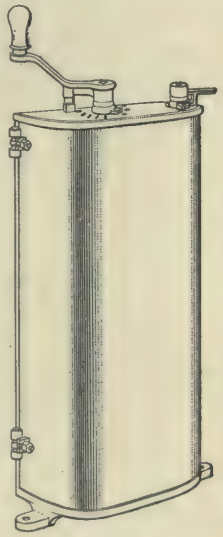


FIG. 2.

In Fig. 3, *1* is the controller handle that turns the controller or power drum *2*; *3* is the reverse handle that turns the reverse drum *4*; *9*, *9* are the fingers or wipers that make contact with the power drum; *6* is the blow-out magnet that sends lines of force across the arcs at each finger and puts the arcs out. The reverse drum and its fingers have no blow-out coil, because the reverse drum cannot be moved while the current is on, and there is therefore no arc there to put out. *7*, *7* are the cut-out switches by means of which a disabled motor may be cut out; *8* is the connection board into which all wires run from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown later in another diagram.

*5*, *5* are the flash guards, made of vulcabeston or other durable insulating material, and they direct the arc, when it is blown, to a place where it can do no harm. The flash

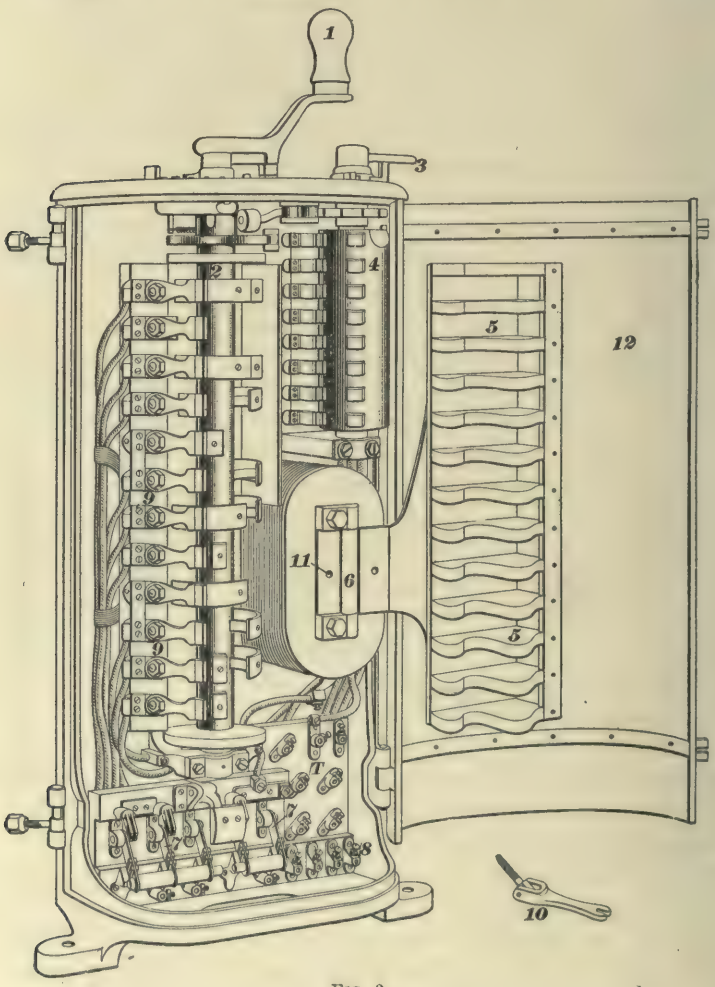



FIG. 3.

guards are mounted on an iron arm that is an extension of the core of blow-out magnet *6*, and this arm extends the full length of the finger board and sends lines of force across each

arc. This arm swings around so as to bring a flash guard in between each pair of fingers and is held in place by means of wing bolt *10*, which screws into hole *11*.

**4. Interlocking Device.**—The two drums interlock through a mechanism called the **interlocking device,** which is arranged so that, when the reverse handle is at the off-position, the controller handle cannot be moved at all, and when the controller handle rests anywhere except on its off-position, the reverse drum cannot be moved at all. Besides this, a circular lug cast on to the controller top makes it impossible to remove the reverse handle except when it is at its off-position. The fact that the reverse handle cannot be turned excepting when the power drum is at the off-position, together with the fact that the reverse handle can be removed only when on its off-position, makes it very nearly impossible for even a novice to leave the reverse drum at go-ahead on one end of the car and try to run from the other end of the car with the reverse drum there at go-ahead also. Go-ahead on one end is back-up at the other end, and when both reverse drums are at go-ahead, it means that the connections are such that an effort is being made to run the car in opposite directions at the same time, with the result that a short circuit follows and the car does not run at all.

Fig. 4 shows how the short circuit is caused. In Fig. 4,

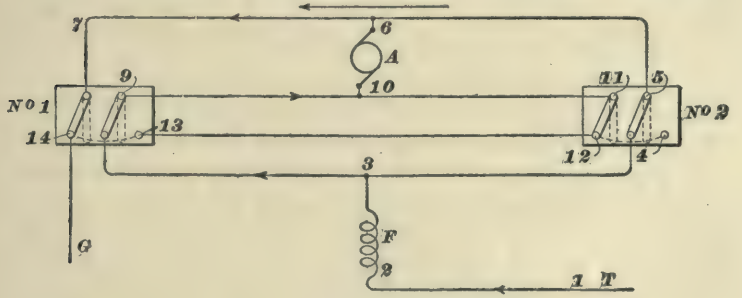



FIG. 4.

*F* and *A* are the field and armature of a motor whose direction of rotation can be controlled by either of the reverse

switches *No. 1* or *No. 2*. It is assumed that when the current enters the bottom brush of the armature, the car moves in the direction indicated by the arrow. If the *No. 1* switch is in the full-line or go-ahead position, and *No. 2* switch is in the dotted or off-position, the current entering at *T* will take the path *T–1–2–F–3–9–10–A–6–7–14–G*, and urge the car ahead; if the *No. 1* switch is at the off-position and the *No. 2* switch is in the full-line position, the current will go into the armature at the top brush holder and urge the car backwards. As long as one switch is off entirely, the other can be moved at will and the direction of motion of the car governed accordingly; but if both switches happen to get on their full-line positions at the same time, the armature is cut out of circuit, and there is a short circuit to the ground by way of the paths *1–2–3–4–5–6–7–14–G* and *1–2–3–9–10–11–12–13–14–G*.

Now the reverse switch on the K2 controller or on any other controller is nothing more nor less than a combination of contact plates and fingers for reversing the direction of the current through either the motor fields or armatures. If both reverse switches are at go-ahead or both are at back-up, then the car will not start, but will blow a fuse and probably burn the controller badly as soon as the power is turned on. If one switch is at go-ahead and the other at back-up, no harm can happen because both switches then make connections that tend to urge the car in the same direction, but it will be impossible to change either switch and run the car without throwing the other switch to the off-position.

**5.** The object in having the reverse switch locked when the power handle is on is this: It is a very bad thing to reverse a car with the power on, as many motormen have learned, because it is not only a great shock to the motors and gearing, but is liable to cause the blowing of the main-motor fuse, leaving the motorman more helpless than ever to stop his car. Suppose, for instance, that the power handle is on notches 4, 5, 8, or 9, where all the starting-coil resistance is cut out of circuit; if, under this condition, the reverse handle is thrown over, the effect is worse than if the pole is

held down until the controller is put on one of these positions, and the pole then put back, allowing the car to start with no resistance in circuit; because when the reverse switch is thrown while the car is in motion, the counter E. M. F., for reasons already explained, adds itself to the line E. M. F., and makes the resulting current larger than the line E. M. F. alone would make it.

Another good reason why the reverse switch should not be thrown while the power is on, lies in the fact that the reverse switch is not built so that it can break very much of an arc, having no arc guards or magnetic blow-out coil, and the result of using it under heavy current is to burn it badly, if indeed it does not flash so badly as to ground the fingers to the controller frame and blow the main-motor fuse. It is the custom on all up-to-date controllers to have the drums so interlock that the reverse switch cannot be thrown when the power is on.

In order to stop a car by means of the reverse switch on an up-to-date controller, it is necessary to throw the power handle off, throw the reverse handle over, and throw the power handle on again. This lets the reversing current in through the starting coil, which limits its value, thereby lessening very much the chances of blowing a fuse, skidding the wheels, or stripping a pinion.

**6.** Fig. 5 shows one form of locking device, which, while not drawn to scale, will show the principle on which the idea is worked out. $A$ is the power-drum shaft and mounted on it, above the electrical part of the drum, is the notched wheel $N$ called the **power-drum index**; $B$ is the reverse drum shaft, and it has the notched wheel $N'$, called the **reverse index.** Screwed to the back of the controller frame is a sleeve $T$, which is bored out to take the spring $S$, and the two plungers $L$, $L'$, which have on one end a teat that is of about the same diameter as the inside of the spring. Plunger $L$ carries a roller $R$ on one end, but $L'$ is simply rounded off on the outside end. In the position shown in the figure, both drums are at the off-position. The power drum cannot be moved around to the notch marked *1*, for as soon

as the drum begins to turn, roller $R$ is forced up the side of the tooth; this shoves $L$ in against spring $S$ and very soon the teats on the two plungers butt against each other and the

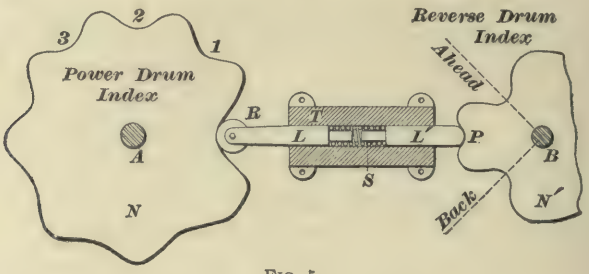



FIG. 5.

plunger $L$ can move no further, thereby preventing the power drum from being turned any further.

The reverse drum, however, can be turned to either the ahead or back position, because the depth of the pocket or notch in the reverse index at the off-position is less than the clearance between the two teats on plungers $L$ and $L'$; so that when the reverse index is moved, the plunger $L'$ forces spring $S$ far enough together to let the index end of plunger $L'$ ride out of the pocket $P$. As soon as the reverse index is turned far enough, $L'$ drops down into one of the deep notches that mark the back or ahead positions; this opens spring $S$ and gives sufficient clearance between the teats on $L$ and $L'$, so that the power drum can now be moved. It must be noticed that the notches, *1*, *2*, *3*, . . . etc. on the power drum are not as deep as the off-position notch. This difference in depth brings about two useful results: the fact that roller $R$ does not drop back so far, leaves spring $S$ under a certain amount of compression, which makes roller $R$ drop into the notches with decision; the other effect is to diminish the clearance between the teats so much as to make it impossible to move the reverse drum while the power is on. Power index $N$ has as many shallow notches in it as there are starting and running positions on the controller. The K2 index has nine shallow notches. These index notches must always be so placed that when the roller is in

the bottom of the notch, the contact tips on the drum are in full flush contact with the fingers.

**7. Controller, or Power, Drum.**—The **power drum** does two things: it cuts resistance into and out of the circuit, and it makes the changes whereby the motors are carried from series to parallel. It is this feature that gives the controller its name of *series-parallel* controller. The power drum is divided into two parts: one part looks after the resistance changes, and the other part looks after the changes from series to parallel. The resistance part of the drum will be taken up first.

In Fig. 6, $T$ is the trolley wire; $C$, the blow-out coil;

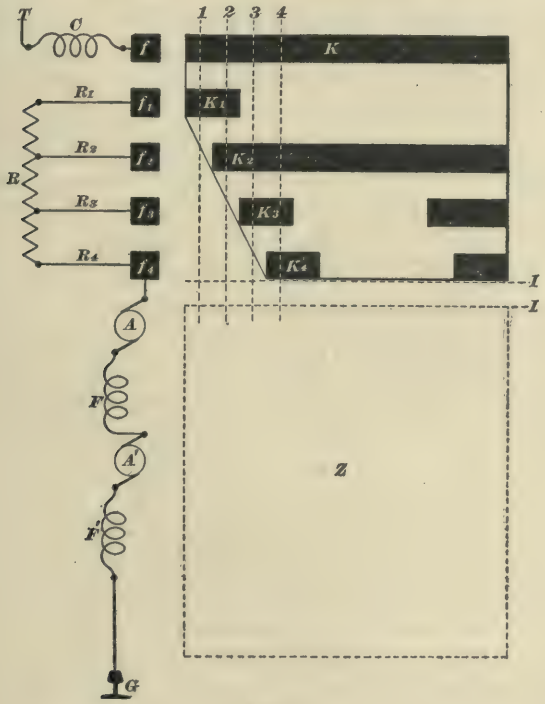



FIG. 6.

$K$, $K_1$, $K_2$, $K_3$, $K_4$, the drum contact rings, which are all connected together; the square blocks $f$, $f_1$, $f_2$, $f_3$, $f_4$ are the

finger stands from which the fingers hang over and rub on the drum contact plates as soon as the drum is turned. $R_1$, $R_2$, $R_3$, $R_4$ are wires leading from the starting coils; $A$, $F$, $A'$, $F'$ are the armatures and fields of the two motors, which are shown connected in series as they really are on the first five points of the K2 controller. The reverse switch, cut-outs, controller wiring, and the lower part $Z$ of the power drum are left out to make things more simple. Each one will be taken up alone, and then they will all be taken up together.

The dotted lines *1*, *2*, *3*, *4* indicate the first, second, third, and fourth notches. The path of the current on the first notch when only fingers $f$ and $f_1$ are touching the drum, is $T$–$C$–$f$–$K$–$K_1$–$f_1$–$R_1$–$R$–$R_4$–$f_4$–$A$–$F$–$A'$–$F'$–$G$. The current, it will be seen, passes through the whole of starting coil $R$. As soon as the drum is put on the second notch, finger $f_2$ touches plate $K_2$ and cuts out that part of the starting coil that is included between $R_1$ and $R_2$, and the path of the current is $T$–$C$–$f$–$K$–$K_1$–$K_2$–$f_2$–$R_2$, through a part of $R$–$R_4$–$f_4$–$A$–$F$–$A'$–$F'$–$G$.

On the second notch, a part of the starting coil is cut out because it is short-circuited by a finger. On the third notch, finger $f_3$ goes into action and cuts out a second part of the coil lying between $R_2$ and $R_3$; and on the fourth notch, finger $f_4$ makes contact with plate $K_4$ and cuts out what remains of the coil. On the fourth notch of the K2 controller, then, the motors are in full series and there is no resistance in circuit save the low resistance of the motors themselves and the counter E. M. F. of the armatures. The fourth notch on the K2 controller is, therefore, a running notch. The fifth notch is also a running notch, but can be best considered in connection with the lower part of the drum here indicated by the dotted outline and letter $Z$.

The contact plates on the right of the drum in Fig. 6 are used when the motors are in multiple, and can therefore be more intelligently considered when the drum connections as a whole are better known. All the contact plates shown in the figure belong to the resistance part of the drum and are

screwed to a single casting, which is not only insulated from the drum shaft, because the shaft is a dead ground, but is also insulated from the lower part of the drum $Z$ by means of an insulating ring indicated by dotted lines $I$, $I$.

**8.** Fig. 7 shows the K2 controller with the power drum fully laid out, but the reverse switch, the motor cut-outs, and the controller connections are omitted. The letters used on the controller fingers are the same as those used on an actual controller. $T$ is the trolley finger; $R_1$, $R_2$, $R_3$, $R_4$ are the resistance fingers. $L_1$ is the free end of the No. 1 shunt, the other end being spliced on to one end of the No. 1 motor field. $L_2$ is the free end of the No. 2 shunt, the other end being spliced to one end of the No. 2 motor field. $F$ and $A$ are the field and armature of the No. 1 motor; $F'$ and $A'$ are the field and armature of the No. 2 motor; $S$ is the No. 1 shunt and $S'$ the No. 2 shunt. $E_1$ is the free end of the No. 1 motor field, and the free end of No. 2 field is grounded. $G$ is the ground finger; *15* and *19* are fingers that ordinarily take wires running from the reverse switch, but as the reverse switch is left out, the wires are in this case run direct. The vertical dotted lines, as in Fig. 6, indicate the several positions assumed by the drum in its passage from the first notch to the ninth notch. There are nine notches, but there are twelve positions. Three of the positions the motorman knows nothing about, further than to know that he can feel a change take place when the controller handle is swept over these positions in going from series to parallel.

**9.** The **first position** is the first notch; the two motors are in series and all the starting coil is in the circuit. The **second position** is the second notch; the two motors are in series and part of the starting coil is cut out. The **third position** is the third notch; the motors are still in series, but more of the starting coil is cut out. The **fourth position** is the fourth notch. The motors are still in series, but all the starting coil is cut out. Thus far, the notches have been considered in connection with Fig. 6 and are entirely rheostatic.

The path of the current on the fourth notch is, as before, *T–C–T–K–$K_1$–$K_2$–$K_3$–$K_4$–$R_4$–A–F–$E_1$–X–3–2–1–15–A′–F′–G*. The **fifth position** is the fifth notch. The motors are in series and all the starting coil is cut out and each field has a shunt in multiple with it.

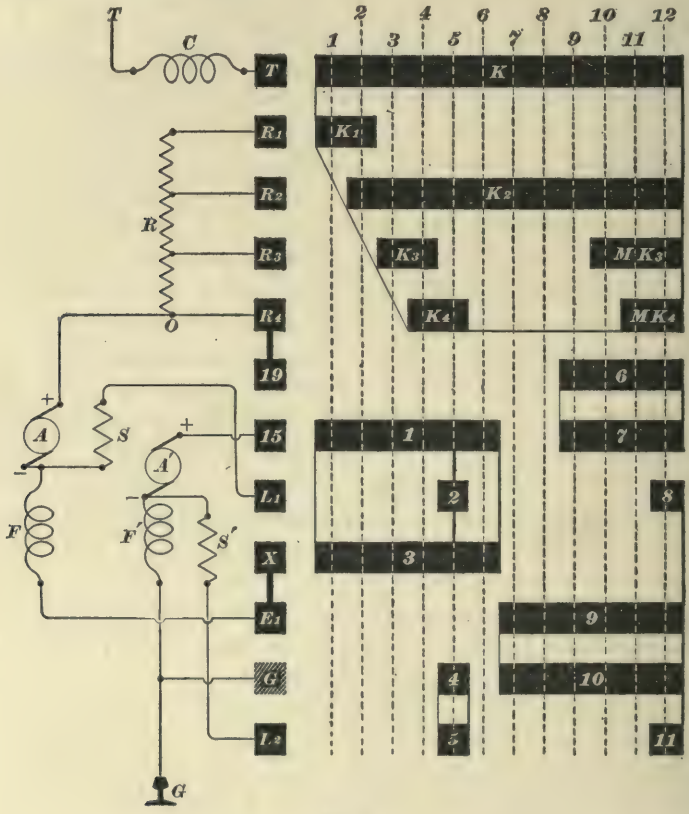



FIG. 7.

**10.** As soon as the fifth notch is reached, three drum plates *2*, *4*, and *5* and three new fingers $L_1$, *G*, and $L_2$ are brought into action. It must be borne in mind that one end of *S* is spliced to one end of *F*, and one end of *S′* is spliced to one end of *F′*. As soon as $L_1$ touches plate *2*, the free end of *S* makes contact with the negative end of *F*, and as soon

as $L_2$ and $G$ touch plates *5* and *4*, the free end of $S'$ and the grounded end of $F'$ are brought together, with the result that when the current gets to point $A-$, it splits and gets to finger *15* through two paths: $A--S-L_1-2-1-15$ and $A--F-E_1-X-3-2-1-15$. When the current gets to point $A'-$, it reaches the ground in two ways: $A'--S'-L_2-5-4-G$ and $A'--F'-G$. The general path of the current on the fifth notch, then, is $T-C-T-K-K_1-K_2-K_3-K_4-R_4-A+-A-$ $-\begin{Bmatrix} F-E_1-X-3-2-1-15 \\ S-L_1-2-1-15 \end{Bmatrix} -A'+-A'-\begin{Bmatrix} F'-G \\ S'-L_2-5-4-G \end{Bmatrix}$ and to the rail. The **sixth position** is not a notch, but is one of the series of combinations used in passing from series to parallel.

It must be noticed that the K2 drum plate runs across the drum and that all the other series-position drum plates do not touch their fingers after the fifth notch is passed. The effect that this has is to cut resistance into the circuit again as soon as the drum leaves the fifth position, with the result that the sixth position is the same as the second; i. e., the two motors are in series, have full fields, and that part of the starting coil that lies between $R_2$ and $R_4$ is in the circuit.

**11.** The path of the current then on the **sixth position** is $T-C-T-K-K_2-R_2$, through the two lower sections of the coil $A+-A--F-E_1-X-3-2-1-15-A'+-A'--F'-G$. There is no mark on the controller top to show where the sixth position is. The seventh position is one of transition, and is not a notch. As the drum leaves the sixth position and goes to the seventh, plates *3* and *1* pass out of service and plates *9* and *10* pass into service; the effect of plates *3* and *1* going out of action is to drop the No. 2 motor out of the circuit entirely, because one end of the motor, the field, goes to the ground, and the other end of the motor, the $A'+$ armature lead, goes to finger *15*, which hangs in the air as soon as plate *1* passes from under it, and the motor can get no current. But the coming into action of plates *9* and *10* gives the current a new path in place of the one of which it has been robbed.

**12.** The path of the current on the **seventh position** is *T–C–T–K–$K_2$–$R_2$–R–A+–A––F–$E_1$–9–10–G*. On the seventh position, then, one motor has been dropped out of the circuit and the car runs on the No. 1 motor in series with two sections of the starting coil. Just at the instant that the fingers are midway in their passage from the sixth position, finger $E_1$ touches plate *9* at the same time that finger *X*, to which $E_1$ is connected, touches plate *3*, with the result that No. 2 motor is momentarily short-circuited just before it is cut out of circuit; but this cannot be felt, because there is so much of the starting coil in ahead of both of the motors.

**13.** The **eighth position** is the same as the seventh position, and it is not a notch. No new plates are cut into action and no old ones are dropped. The eighth position is a useful one, however, in that it gives the drum more distance to travel in its passage from the series to the multiple positions.

**14.** The **ninth position** is the sixth notch. The two motors are in multiple, have full fields, and are in series with two sections of the starting coil. The arrival of the drum on the ninth position brings plates *6* and *7* into action, and enables the No. 2 motor to get current through finger *15*. The current divides between the two motors at the point *O* where the resistance wire splices on to the *A+* armature wire; from there to the ground are two paths; one of them is *O–A+–A––F–$E_1$–9–10–G*, and the other path is *O–$R_4$–19–6–7–15–A'+–A'––F'–G*. The ninth position is a marked notch, but is not a running notch.

**15.** The **tenth position** is the seventh notch, but it is not a running notch. The two motors are in multiple and are in series with but one section of the starting coil, because finger $R_3$ touching plate $MK_3$ cuts out that part of the coil which lies between $R_2$ and $R_3$ wires.

**16.** The **eleventh position** is the eighth notch, and it is a running notch. The motors are in multiple, have their full fields, and all the starting coil is cut out of the circuit.

**17.** The **twelfth position** is the ninth notch, which is also a running notch. The ninth notch is the same as the eighth notch, excepting that plates *8* and *11* coming into

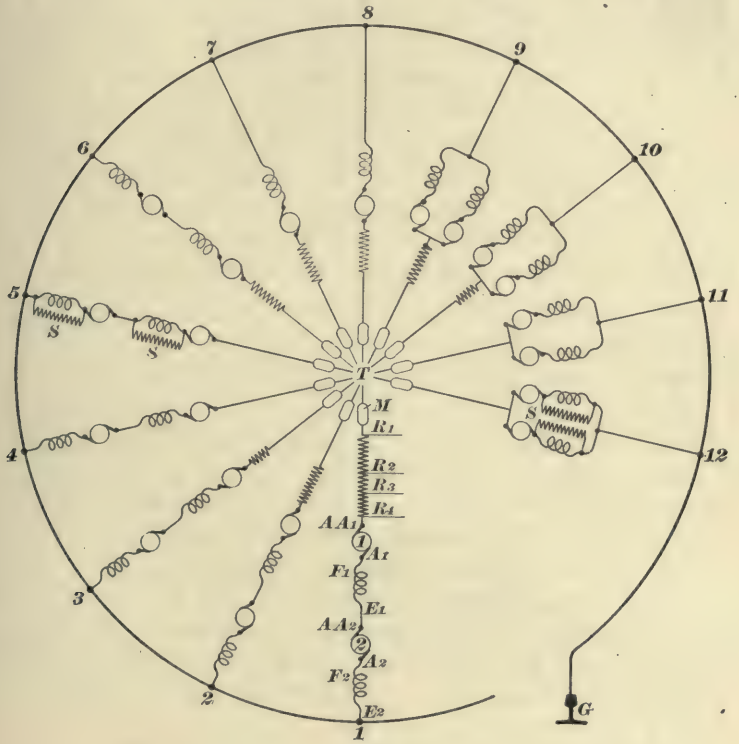



FIG. 8.

action put shunts on both of the motor fields. The combinations at the various positions are indicated by the diagrams in Fig. 8.

**18. The Notches.**—On the top of every controller will be found cast some little ribs, which, in conjunction with the pointer carried on the power-drum shaft, enable the motorman to tell when the drum is on a notch. On controllers of some makes, this pointer is cast on the handle itself, but this is not a good idea, because as soon as the fit between the handle and the shaft gets loose, the pointer indicates

wrongly. Besides the ribs or dashes on the top, is usually found the word "off," to indicate the off-position of the drum, and the pointer on the shaft should always point at this word "off" before leaving the car and before putting the pole on a car that has been left standing for any length of time. Ordinarily, a man has a right to assume that the controller shaft is at the off-position if both handles are removed, but this assumption is not always safe, because barn men and inspectors have a habit of turning the shafts around with a wrench, instead of getting a pair of handles, and sometimes they fail to turn the shaft back to the off-position when they are through working on the drums.

**19.** Some of the ribs on top of a controller are long and some of them are short. The long ribs indicate the notches on which it is safe to run any length of time; the short ribs indicate the notches to be used only in starting and in going from series to parallel. On the K2 controller there are four of these long ribs; two of them are for the series combination and two for the multiple. The two long ribs in series indicate the fourth and fifth notches; those in multiple indicate the eighth and ninth notches. The K2 controller has, then, four running notches: the fourth, fifth, eighth, and ninth, and none of the other notches should be run on for any length of time, for it is a waste of power and an abuse to the starting coil.

**20.** Fig. 9 shows the layout of the K2 controller top.

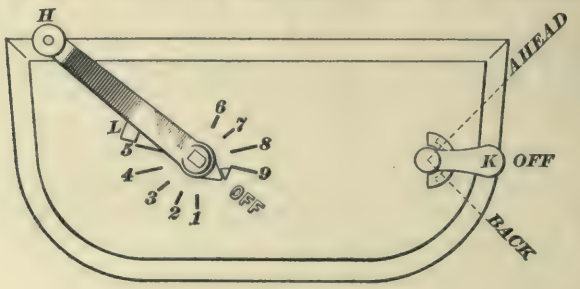



FIG. 9.

*H* is the power-drum handle resting on the off-position; *K* is

the reverse handle, also at the off-position. If *K* is moved ahead, the car will move ahead as soon as *H* is moved until its pointer points to *1*; if *K* is moved back, the car will move back. *L* is a lug against which a projection on the handle bears when the handle is moved to the ninth notch or to the off-position. On old-time types of controllers, it was necessary to watch the pointer very carefully to avoid running in between the notches, thereby burning the controller tips and fingers, but, on up-to-date controllers, the roller that plays into the notches on the drum index is acted on by a spring that is strong enough to force the drum around as soon as the roller begins to descend into a notch. As soon as a man gets used to the working of the index, he wonders how he ever could have run anywhere but right on the notch. Only "green" men can run between notches.

**21. Reverse Drum.**—Fig. 10 (*a*), (*b*), and (*c*) shows the layout of three types of reverse drum; (*a*) is an old-style reverse switch, (*b*) is a reverse drum for a single motor, and (*c*) is a reverse drum for two motors. In (*a*), the full-line position of the blades lets the current into the left-hand side of the armature and the armature turns so as to urge the car ahead. If the blades are thrown to the dotted position, the current enters the armature at the left-hand side and turns it so as to urge the car back.

**22.** In Fig. 10 (*b*), *1*, *3*, *4*, *6* are the finger stands and *2*, *5*, *7*, *8*, *9*, *10* are the plates on the reverse drum. In the actual drum, plates *2* and *5* are on one side of the fingers and plates *7*, *8*, *9*, *10* are on the other side, so that when the reverse handle is shoved ahead, the fingers engage one set of plates, and when the reverse handle is shoved back, the fingers engage the other set of plates. When the drum is in such a position as to place plates *2* and *5* under the fingers, the path of the current is *T*–*1*–*2*–*3*–*A*+ –*A*– –*4*–*5*–*6*–*F*–*G*; the current enters the left-hand side of the armature and urges the car ahead; but when the drum is turned so that plates *7*, *8*, *9*, *10* come under the fingers, the current goes into

the right-hand side of the armature, by way of path *T*–1–7–9–4–*A*– –*A* + –3–8–10–6–*F*–*G*, and the car backs.

**23.** Fig. 10 (*c*) shows the drum for two motors, which is nothing more nor less than two single-motor drums put on

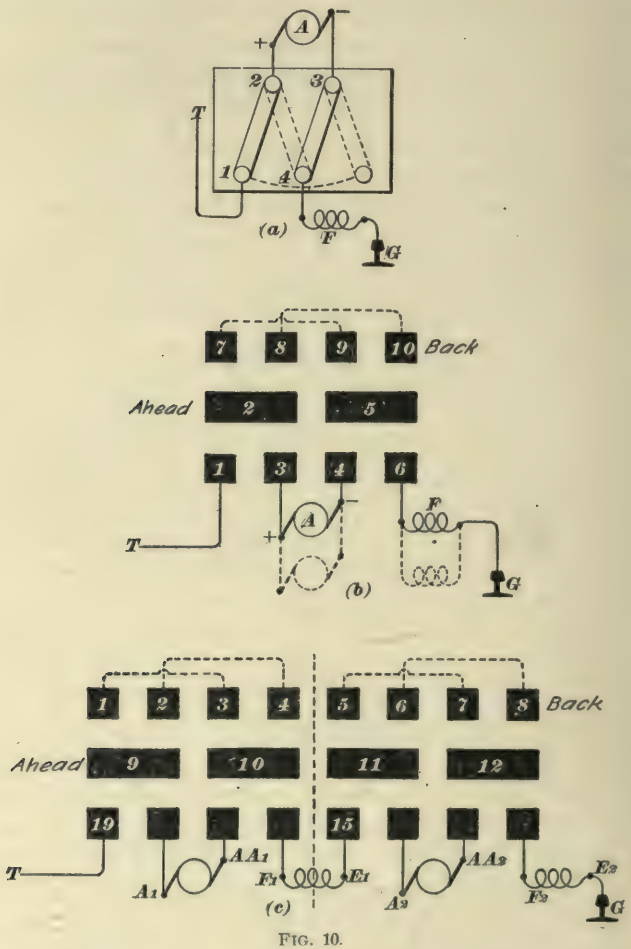



FIG. 10.

the same shaft; in fact, the single-motor drum can be made to serve for two motors, if the second motor is connected as shown by the dotted line in Fig. 10 (*b*) and it is intended to

run the motors permanently in multiple. Such a scheme is actually used on cars equipped with four motors. The main objection to using a single-reverse switch or drum for two motors, on a car having only two motors, is that one motor cannot be cut out without disconnecting its leads.

In Fig. 10 (*c*), the fingers have the same names as they have in the K2 controller and the path of the current on the go-ahead position is *T–19–9–$A_1$–$AA_1$–10–$F_1$–$E_1$–15–11–$A_2$–$AA_2$–12–$F_2$–$E_2$–G*. On the back position, the path is *T–19–1–3–$AA_1$–$A_1$–2–4–$F_1$–$E_1$–15–5–7–$AA_2$–$A_2$–6–8–$F_2$–$E_2$–G*.

**24.** In Fig. 10 all devices except the reverse switch have been left out and the wires run direct so that the path through the reverse switch can be more easily followed, but in Fig. 11 all the devices except the motor cut-outs and the connecting board are shown in the circuit. The letters and the figures are the same as in Fig. 7, but there are more of them. When the reverse drum is on the ahead position, the path of the current on the first notch is *T–C–T–K–$K_1$–$R_1$–O–19–1′–$A_1$–A–$AA_1$–2′–$F_1$–F–$E_1$–X–3–2–1–15–15–3′–$A_2$–A′–$AA_2$–4′–$F_2$–F′–G*, and when the reverse drum is on the back position, the path of the current is, on the first notch, *T–C–T–K–$K_1$–$R_1$–O–19–a–c–$AA_1$–A–$A_1$–b–d–$F_1$–F–$E_1$–X–3–2–1–15–15–e–g–$AA_2$–A′–$A_2$–f–h–$F_2$–F′–G*. When the power drum reaches the fifth notch, drum plates *2*, *4*, and *5* make contact, throwing shunt *S′* across field *F′* and shunt *S* across field *F*. The current, on getting to *x*, then splits between *F* and *S*, and, at *x′*, it splits between *F′* and *S′*. Also, when the power drum reaches the ninth notch, the current splits at point *O*; part of it takes the path *O–19–1′–$A_1$–A–$AA_1$–2′–$F_1$–F–$E_1$–9–10–G*; i. e., through the No. 1 motor, and the other part takes the path *O–$R_4$–19–6–7–15–15–3′–$A_2$–A′–$AA_2$–4′–$F_2$–F′–G*, through the No. 2 motor.

**25. Motor Cut-Out.**—In the lower part of the K2 controller, just below the power drum and its finger board, are to be found the two motor cut-out switches, used to run the

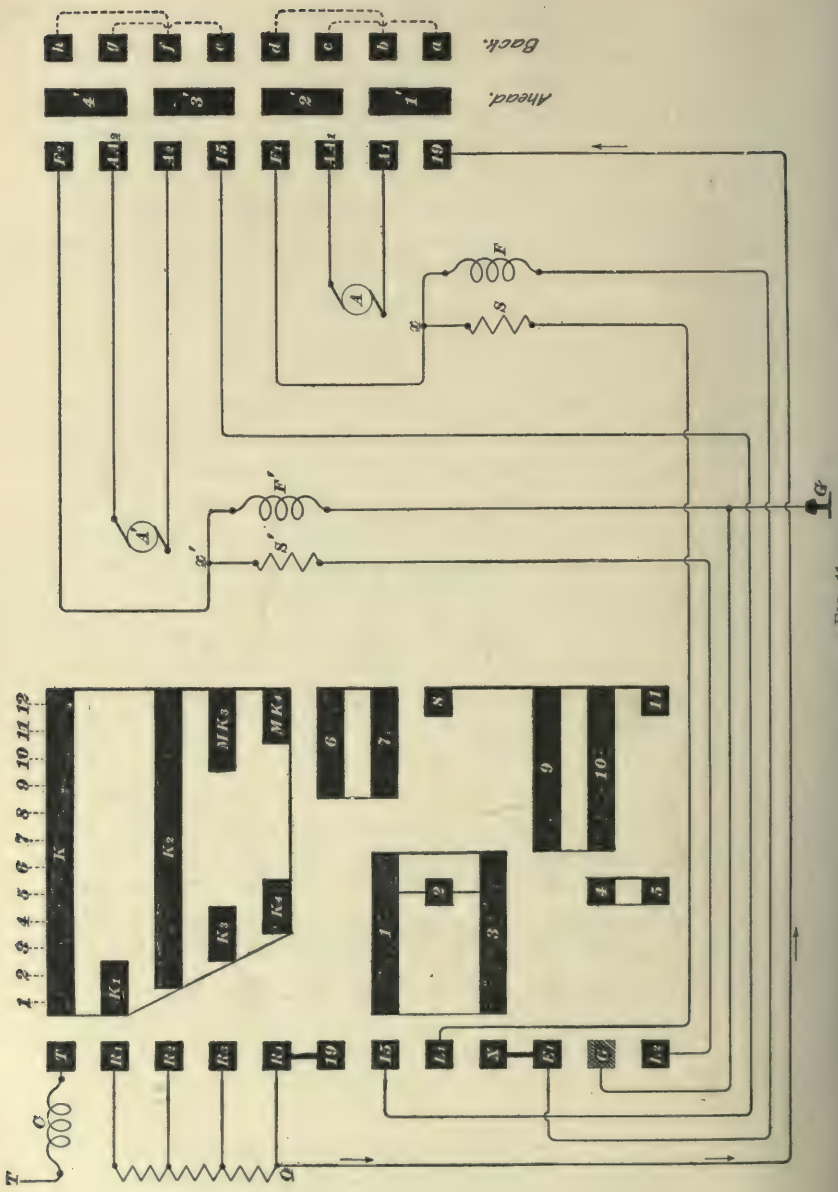

Back.
Ahead.
F
S
F'
S'
A
V
K
K1
K2
MK3
MK4
K3
K4
T
C
R1
R2
R3
R4
19
15
L1
X
E1
G
L2
1
2
3
4
5
6
7
8
9
10
11
12

FIG. 11.

car on one motor if the other motor, or any part of its circuit, gives out. These two switches may be thrown up or down, and when the car is in good shape and both motors in use, both switches should be down. Inside the door of every K2, K10, or K11 controller are found two cards that tell how to cut out a faulty motor; one motor is called the No. 1 motor and the other, the No. 2 motor; the No. 1 motor is the motor on the fuse-box end of the car. On the No. 1 controller, one card reads: "*To cut out motor No. 1 (the motor nearest this end of car), throw up left-hand switch as far as it will go. To cut out motor No. 2 (motor nearest other end of car), throw up right-hand switch as far as it will go.*" On the inside of the door on the No. 2 controller, one card reads: "*To cut out motor No. 1 (motor nearest other end of car), throw up left-hand switch as far as it will go. To cut out motor No. 2 (motor nearest this end of car), throw up right-hand switch as far as it will go.*" The motor cut-out instruction cards read differently on the two ends of the car, because, on the front end of the car, the No. 1 motor is the front motor, and the No. 2 motor is the rear motor; but on the rear end of the car, the No. 2 motor is the front motor and the No. 1 motor the rear motor.

**26.** The shaft of the power drum has on it a stop that is interfered with by a pin operated by the cut-out switch in such a way that when either switch is thrown up, the power drum cannot be moved past the fifth notch. If this were not done, the result would be to cause a short circuit on the ninth position, by way of the path, $T$–$K_2$–$R_3$–$O$–$R_4$–*19–6–7–15*–$N$–$G$ (Fig. 15), if the good motor should happen to be the No. 1 motor. If the good motor happened to be the No. 2 motor, as soon as fingers $E_1$ and $G$ made contact with plates *9* and *10*, Fig. 15, there would be a dead short circuit across the line. Why such would be the case can be seen by considering the details of a cut-out switch.

**27. Details of Cut-Out Switch.**—The general idea of a cut-out switch has been taken up in *Car Equipment*, Part 5.

Figs. 12, 13, and 14 give the connections of the K2 cut-out switches under all conditions, and Fig. 15 is a diagram of the controller circuits complete, all except the connecting board. In Fig. 12, both motors are cut in; in Fig. 13, the No. 1 motor is cut in and the No. 2 motor cut out; in Fig. 14, the No. 1 motor is cut out and the No. 2 motor cut in. In Fig. 12, the path of the current is *T–k–19–$A_1$–$AA_1$–$F_1$–$E_1$–$E_1$–l–n–15–$A_2$–$AA_2$–p–$F_2$–G*. The two shunts are left open-ended, because the free ends go to parts of the controller not shown.

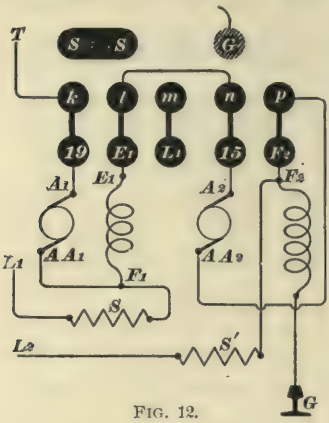



FIG. 12.

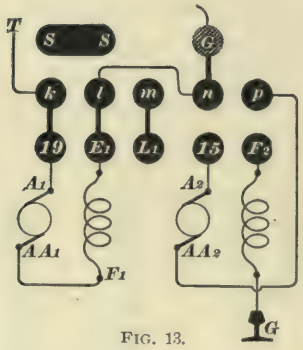



FIG. 13.

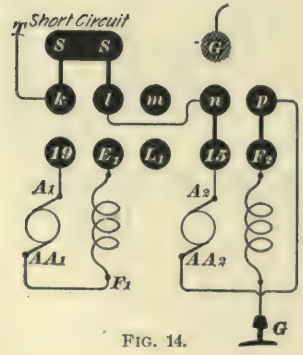



FIG. 14.

**28.** Fig. 13 shows No. 1 motor cut in and No. 2 motor cut out. The current, whose path is *T–k–19–$A_1$–$AA_1$–$F_1$–$E_1$–l–n–G*, instead of passing through the No. 2 motor, passes to the ground through block *G*. Fig. 14 shows the No. 1 motor cut out and the No. 2 motor cut in, and the path of the current is *T–k–SS–l–n–15–$A_2$–$AA_2$–p–$F_2$–G*. It will be noticed that the current, instead of going through the No. 1 motor, passes through the short-circuiting strip *SS*; as soon as the cut-out switch is thrown up, the two ends of the No. 1 motor are left hanging in the air, so to speak, and the faulty No. 1

motor can have absolutely no effect on the rest of the circuit. The circuit has been opened at both ends of the No. 1 motor and the current given a new path through the short-circuiting strip *SS*. In the case of the No. 2 motor, practically the same thing is done, but since the negative end of the motor circuit is grounded (the negative end of its field coils being permanently connected to either the motor frame or the ground wire), it is necessary to open but one end of the motor circuit and lead the current to the ground by means of the wire that formerly went to the positive end of the motor; this wire is the one that connects blocks *l* and *n*.

**29.** In Fig. 15, both switches are thrown down, so that both motors are cut in and the path of the current on the first notch is *T–C–T–K–$K_1$–$R_1$–O–k–19–19–1′–$A_1$–A–$AA_1$–2′–$F_1$–F–$E_1$–l–$E_1$–3–2–1–15–n–15–15–3′–$A_2$–A′–$AA_2$–4′–$F_2$–p–$F_2$–F′–G*. If the No. 1 switch is thrown up to the dotted position, the No. 1 motor is cut out and the path of the current is *T–C–T–K–$K_1$–$R_1$–O–k–SS–l–$E_1$–3–2–1–15–n–15–15–3′–$A_2$–A′–$AA_2$–4′–$F_2$–p–$F_2$–F′–G*. If the No. 2 switch is thrown up to the dotted position, the No. 2 motor is cut out and the path of the current becomes *T–C–T–K–$K_1$–$R_1$–O–k–19–19–1′–$A_1$–A–$AA_1$–2′–$F_1$–F–$E_1$–l–$E_1$–3–2–1–15–n–G–G*.

If, by any hook or crook, both switches should be thrown up, thereby cutting out both motors, the path of the current would be *T–C–T–K–$K_1$–$R_1$–O–k–SS–$E_1$–3–2–1–15–n–G–G*. The resistance coil alone would be in circuit, the car could not start and any advancement of the power handle would cause the main-motor fuse to blow unless some part of the controller should blow first. Such an act as cutting out both motors at the same time is an unusual one, but still it has happened with bad results, and, as the old saying goes, "forewarned is forearmed." So do not try to cut out both motors at the same time. It must be clearly understood that a cut-out switch must be used only when the power is off. The switch is not built to break any arc, and any attempt to make it do so is apt to result in not only the

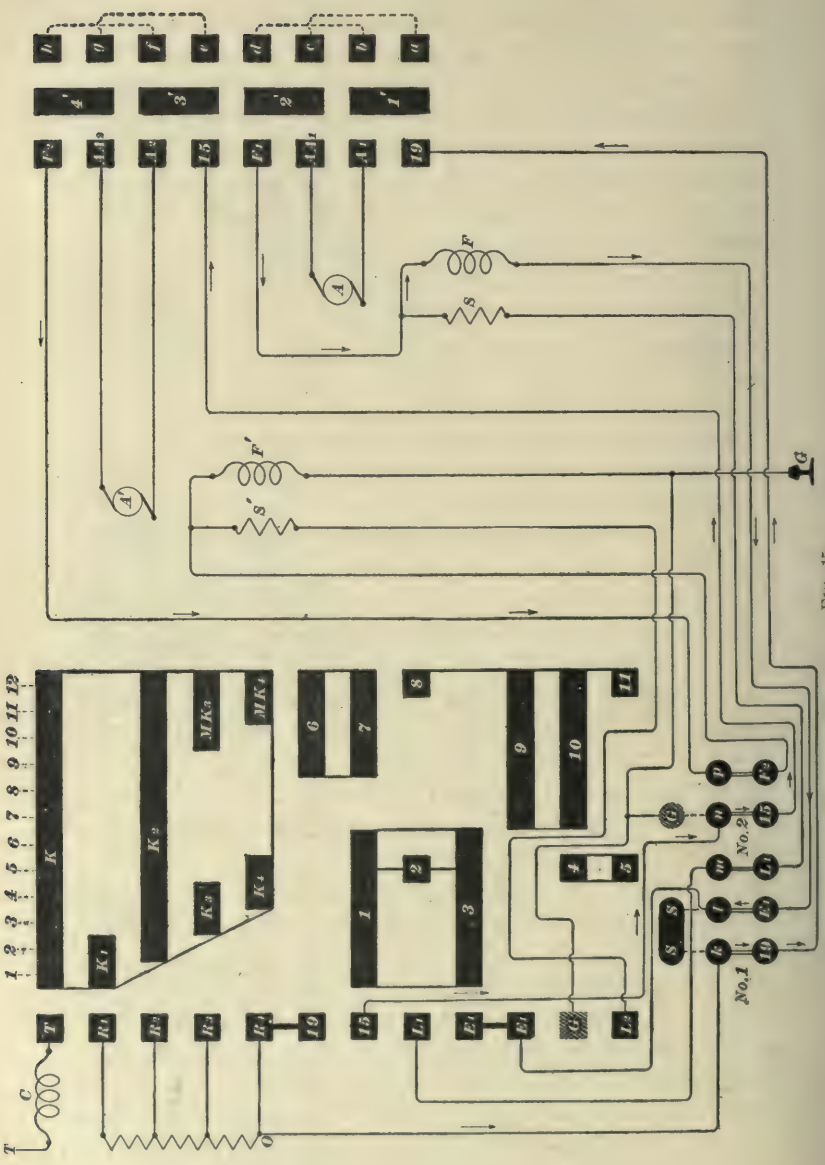



FIG. 15.

destruction of the switch itself, but in injury to the operator's eyes.

The cut-out switches on all controllers made by different companies vary somewhat in detail and appearance, but they all do the same thing, namely, drop the motor out of the circuit entirely and put a metal path in its place, so the current will have a bridge over which it can cross in order to reach the motor that is not to be cut out.

**30. Connecting Board.**—The **connecting board** is a board on which is mounted a number of connecting posts, into which run the wires from the motors and other devices necessary to operate an electric car. In Fig. 3, $T$ is the connecting board, and the car wires come up to it through an oblong hole in the bottom of the controller. Each connecting post has two wires run to it; one wire is part of what is called the *internal wiring* of the controller, and connects the post to one of the power-drum fingers, to one of the reverse fingers, or to one of the cut-out switches, as the case may be; the other wire is one of the external wires and comes from a motor or some other device under the car.

**31.** Fig. 16 shows how the connecting posts on the K2 connecting board are marked. The $E_1$, $L_1$, $F_2$, and $G$ posts are parts of the cut-out switches, but they are also parts of the

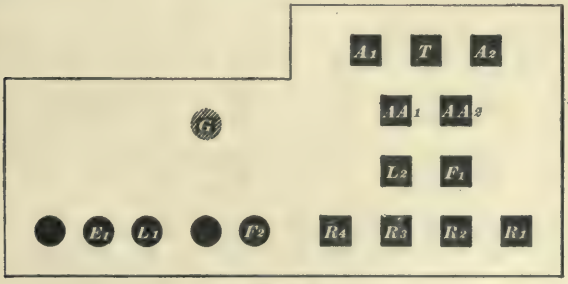



FIG. 16.

connecting board, as they take wires from the car-wiring hose. Post $T$ takes the main-trunk trolley wire; post $A_1$ takes the wire from one side of the No. 1 armature; and post $AA_1$ takes the wire from the other side of the No. 1 armature. Post $A_2$

is one side of the No. 2 armature, and $AA_2$ is the other side of the same armature. $L_1$ is the free end of the No. 1 shunt and $L_2$ is the free end of the No. 2 shunt. One end of the field on No. 1 motor goes to $F_1$ and the other end of the same field goes to post $E_1$. One end of the No. 2 motor field goes to post $F_2$ and the other end of the field, which is sometimes marked $E_2$, goes to no post at all, but connects directly to the ground wire that goes to post $G$. Posts $R_1, R_2, R_3, R_4$ take the resistance wires. All wires that go into any of the above posts run the full length of the car from one controller to the other, and the leads from the motors and other devices tap on somewhere, wherever it is most convenient.

**32.** On a car equipped with two K2 controllers, then, there are 14 wires running the full length of the car, and any $A$, $L$, $E$, or $F$ wire having the figure *1* after the letter belongs to the No. 1 motor or its shunt, and the figure *2* after the letter shows the wire to be part of the No. 2 motor circuit. In other words, $T$ and $G$ are the trolley and the ground; $R_1$, $R_2$, $R_3$, and $R_4$ are the resistance wires; $A_1$, $AA_1$, $F_1$, $E_1$, and $L_1$ are the No. 1 motor wires; and $A_2$, $AA_2$, $F_2$, $E_2$ or $G$, and $L_2$ are the No. 2 motor wires. Now, in an actual controller, these letters are burned or stamped into the wooden connecting board alongside the post or block to which they belong, and, on a new board, they are very easy to see, but after a board is old and has been scraped and painted or shellaced several times, the letters are hard to see and it is much more satisfactory to study out the posts on the board until one knows their positions by heart. A man that is perfectly familiar with the connecting board on a controller can connect one up in two-thirds the time that it takes a man that has to look at a drawing or blueprint; and any motorman that knows his connecting board can, in case of a grounded controller, take the trolley wire out and bend it back while some man that knows less is finding out which wire to take out.

**33.** Fig. 17 shows the internal connections of the K2 controller. Every man that works on controllers should have

a good idea as to where each wire goes, so that he may be able to locate an open circuit wherever it may be. Open circuits are not always to be found in the motors and other

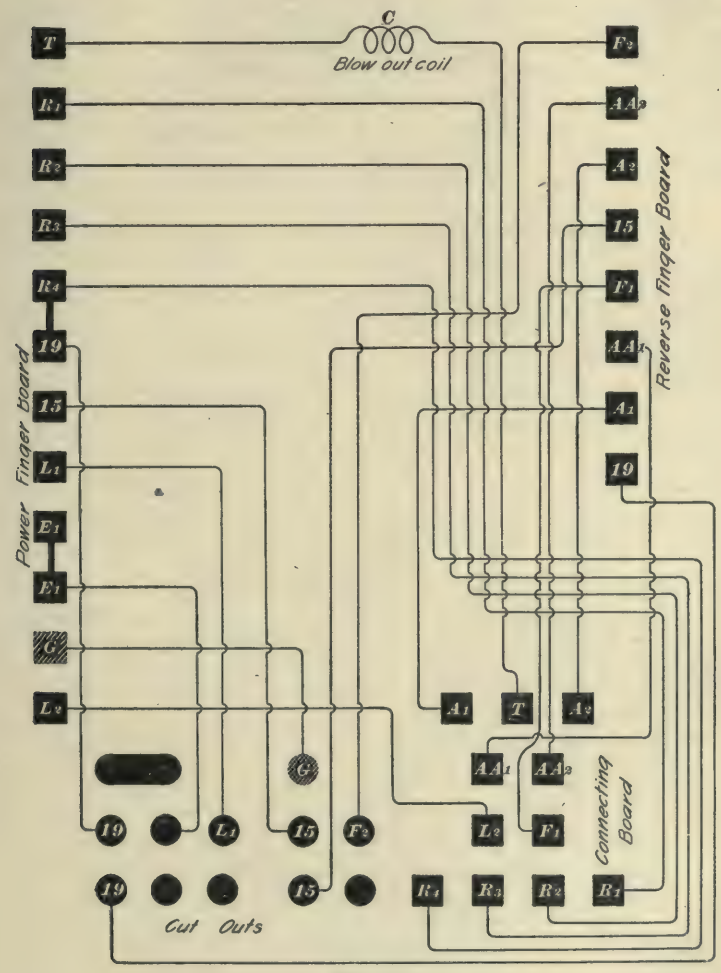


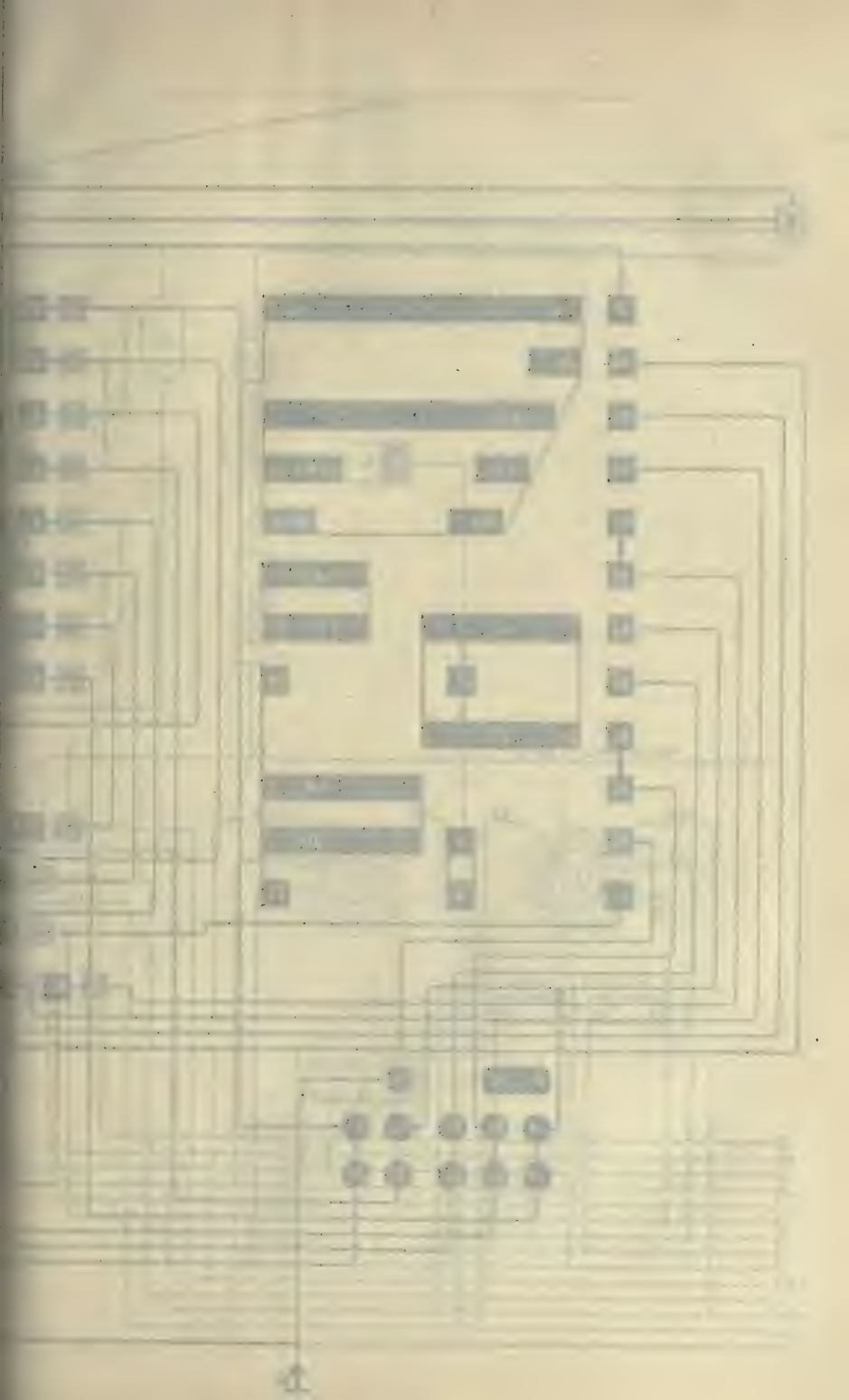

FIG. 17.

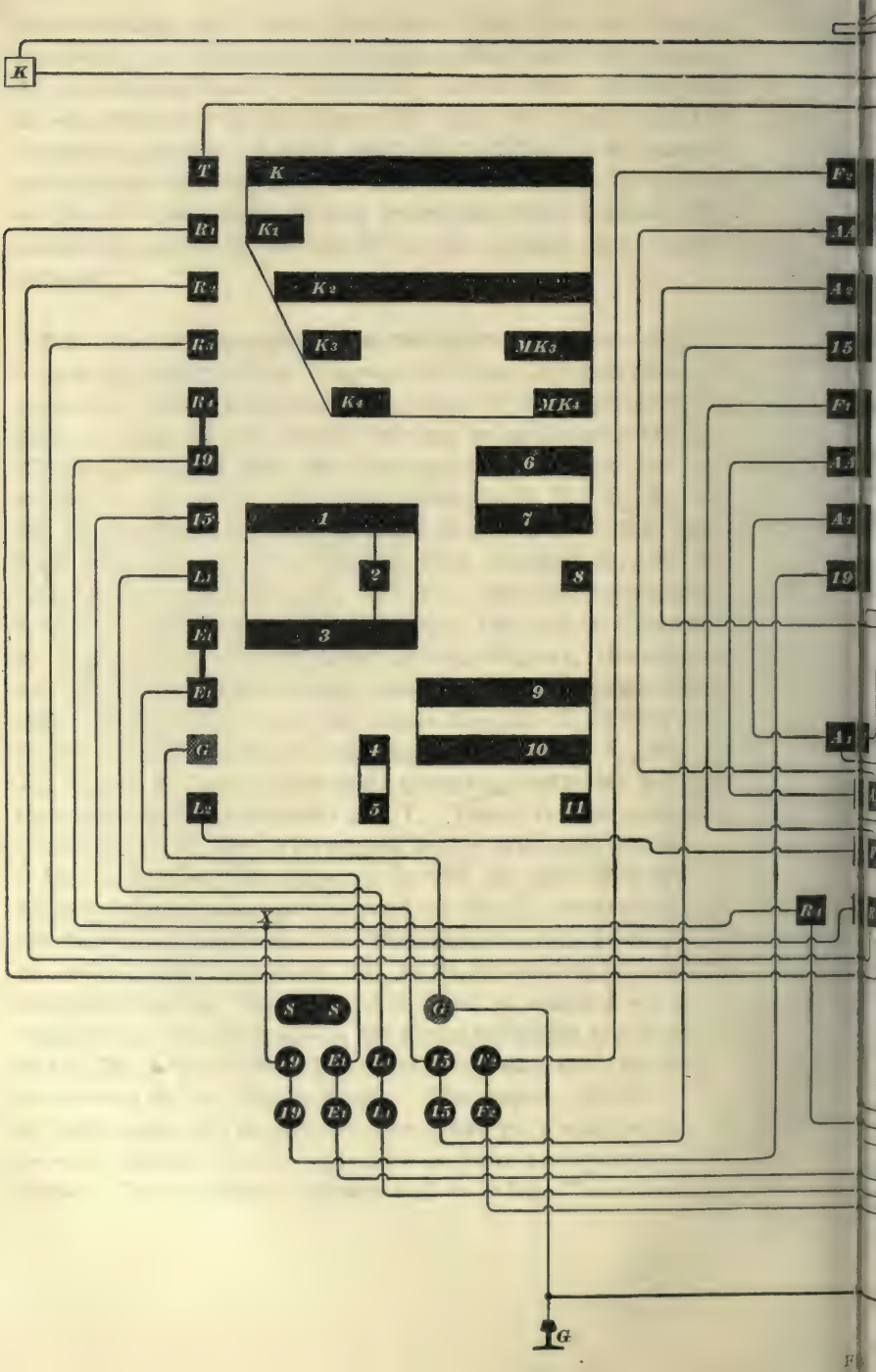
devices under the car, but are often to be found in the controller itself; there may be a loose or broken finger, or an internal wire may be burnt off entirely or worked loose from

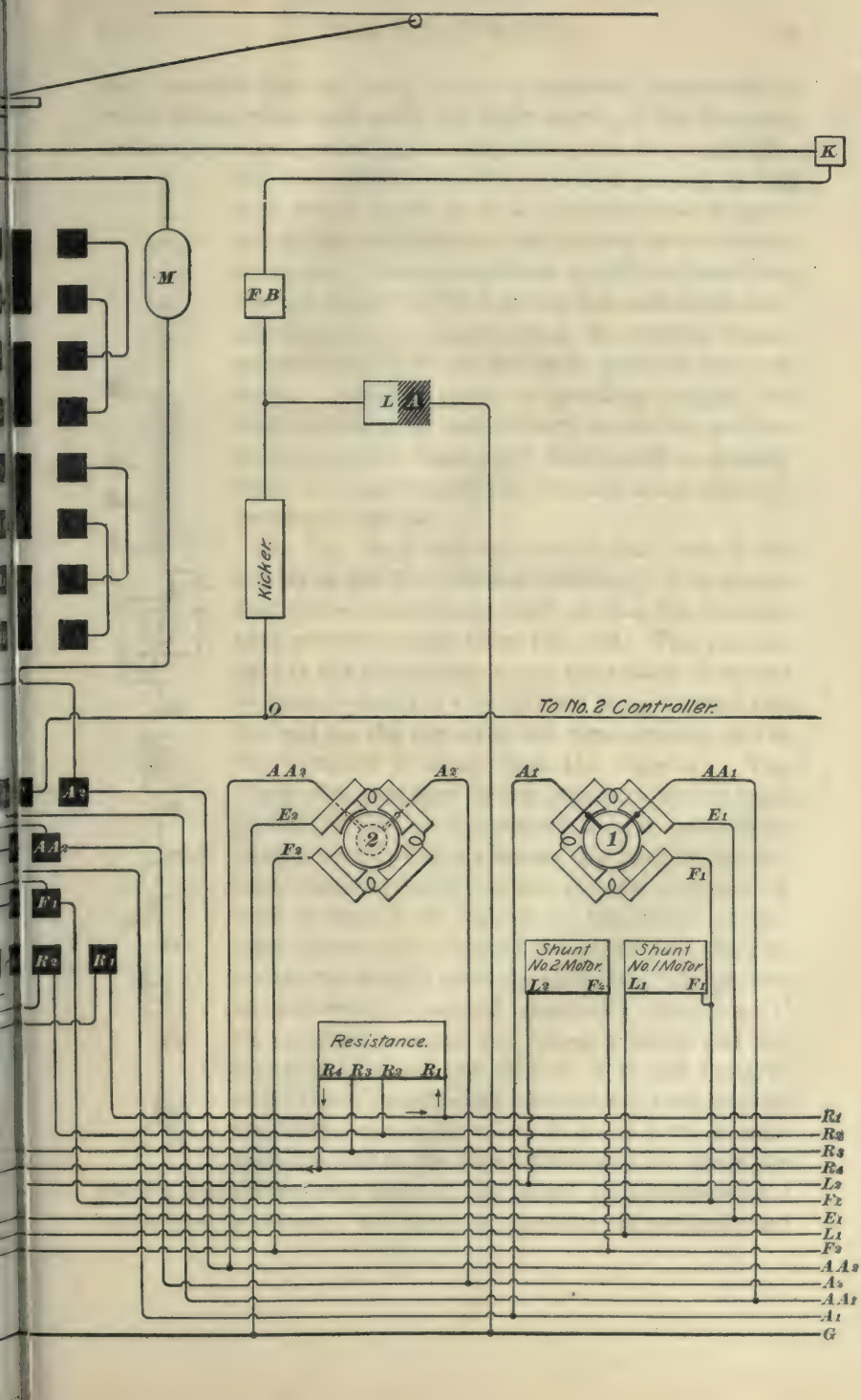
its connecting post. Sometimes one of the car wires, through some jolt, jar, or undue strain, gets pulled out of its place on the connecting board. Of course, such a fault as this can be seen by opening the controller door and inspecting the connecting board. A very good rule to follow in all cases of trouble is to first see if the source of trouble can be located by the eye and hands before trying any finer methods, for often the source of trouble is on the surface, and readily detected.

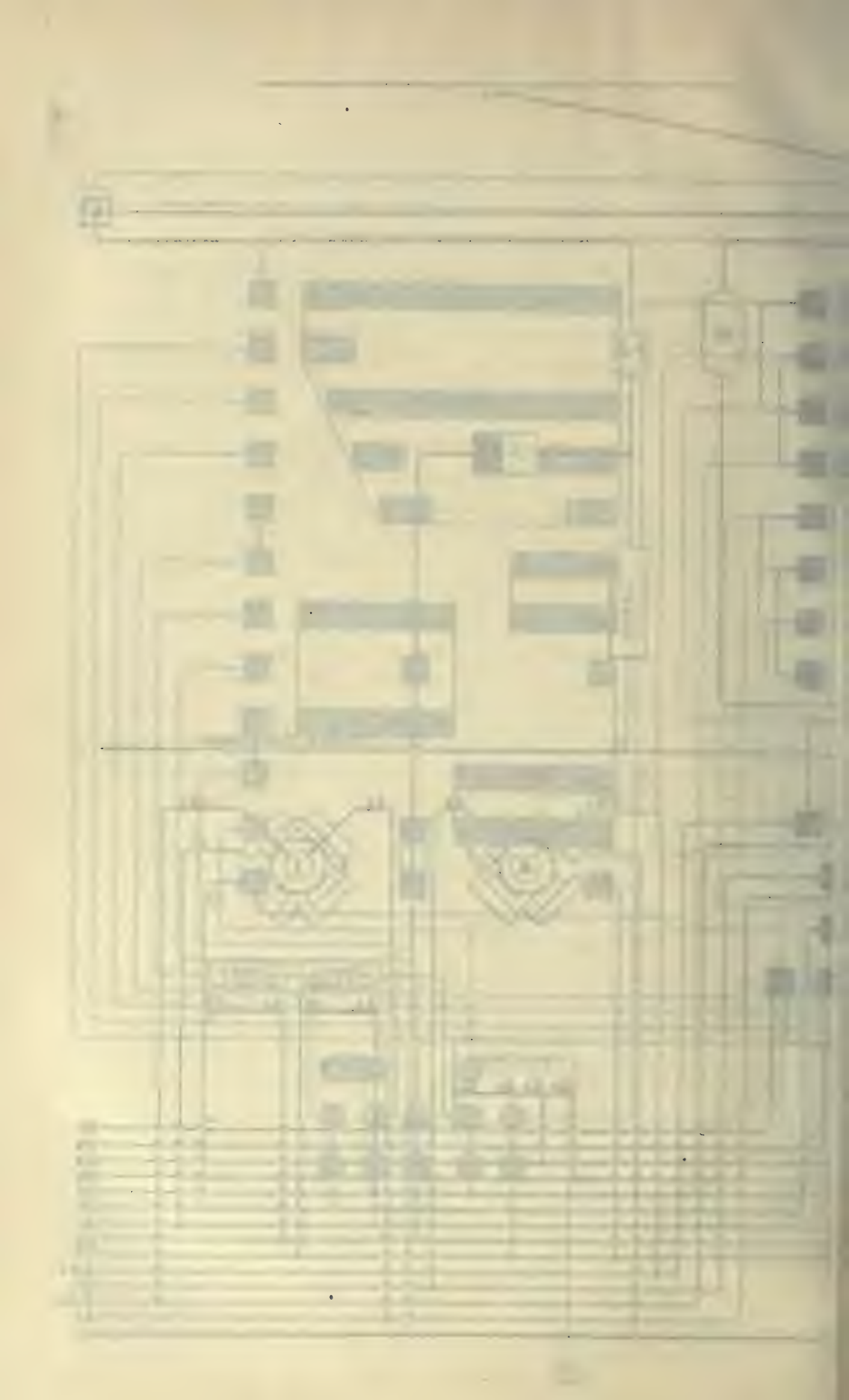
**34. Car-Wiring Diagram for K2 Controller.**—Fig. 18 is a regular car-wiring diagram for the K2 controller; it shows not only the internal connections of the controller, but also the wires to the several devices on and under the car. These devices include the two motors *1* and *2*; the two shunts $L_2$, $F_2$, and $L_1$, $F_1$; the starting coil $R_1$, $R_2$, $R_3$, $R_4$; the hood switches $K$ and $K$; the fuse box $FB$; the lightning arrester $LA$; the kicking coil, marked *kicker;* the blow-out magnet coil $M$; and the controller electrically complete including its several parts, the power drum and its fingers, the reverse drum and its fingers, the cut-out switches and the connecting board. The diagram shows only one controller, but the connecting in of another controller is only a matter of running broken wires $R_1$, $R_2$, $R_3$, $R_4$, $L_2$, $F_1$, $E_1$, etc. to the same posts on controller No. 2 as they come out of controller No. 1. There is one exception to this rule and that is in regard to the armature wires.

By looking at the diagram, it will be seen that the $A_1$ finger of the reverse switch runs to the $A_1$ connecting post on the connecting board, but the car wire going from the $A_1$ connecting post is marked $AA_1$ at its broken end; also, the car wire leading from the $AA_1$ post is marked $A_1$ at its broken end; in other words, the armature wires are reversed in the No. 2 controller. The same is the case with the armature wires on the No. 2 motor. The reason of this is that at both ends of the car, the car must go ahead when the reverse handle of the controller on that end points to go-ahead. Now "ahead" on one end is "back" on the other




K
T
K
K1
K2
K3
MK3
K4
MK4
R1
R2
R3
R4
19
15
L1
E1
E2
G
L2
1
2
3
4
5
6
7
8
9
10
11
F2
A4
A2
15
F1
A3
A1
19
R1
X
S S
G
19 E1 L1 15 F2
19 E1 L1 15 F2
G


K
M
F B
L A
Kicker.
O
To No. 2 Controller.
A A2
A2
E2
F2
2
A1
A A1
E1
F1
1
A2
A A2
F1
R2
R1
Shunt No 2 Motor.
L2 F2
Shunt No 1 Motor
L1 F1
Resistance.
R4 R3 R2 R1
R1
R2
R3
R4
L2
F2
E1
L1
F2
A A2
A2
A A1
A1
G



end, because the car must move in opposite directions to move ahead from both ends. In other words, if the two controllers were connected up exactly alike, the car would follow the indications of the reverse handle on one end, but it would go in a direction exactly opposite to the indication of the reverse switch on the other end. Such a condition would not mean that the car could not be run, but it would mean simply that to run the car ahead, the reverse handle would have to be in the back position and vice versa. Now, in times of pending danger, the motorman's most involuntary move is to pull his reverse handle back, so if the handle is already back, it is apt to confuse him and make him lose control of his car.

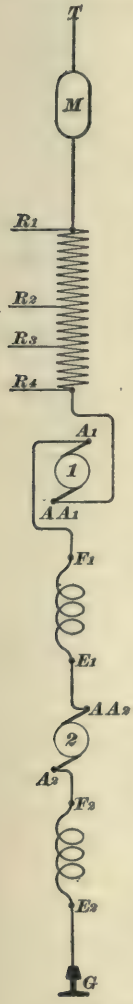


FIG. 19.

In Fig. 18, it will be noticed that one of the circles in the No. 2 motor is dotted. This means that there is a circular part on the No. 2 motor that cannot be seen from this end. The circular part is the commutator and the reason it cannot be seen is that the two motors being turned end for end on the car axle, the commutator on the No. 2 motor is away from the observer. The effect that this has on the connections has been alluded to in *Car Equipment*, Part 5, but can be clearly seen in Fig. 19, where the path of the current from the trolley to the ground is shown; if both motors were swung on the axles so that their pinion ends pointed the same way, the two armatures would turn the same way; if the two motors were connected up exactly alike, i. e., if the current entered the forward brush and the top field lead on one motor, it would have to enter the forward brush and the top field lead on the other motor in order to have both motors urge the car in the same direction; but since the motors are turned end for end, the same connection would cause the armatures to turn in opposite directions and

thereby work against each other. To avoid this, the current is made to flow through one armature in the opposite direction to that in the other, as shown in Fig. 19.

Assuming that there are two motors to be connected up on a car, that neither of them is connected, and that there is no blueprint or drawing to go by, and further assuming that the wiring cable is in place and connected up to the controllers, and that the motor cable leads, properly tagged, are sticking out of the hose ready to be connected to the motors, the way to go about it is as follows: It is known that all motor leads tagged $A$ are to go to an armature, and that all motor leads tagged $E$ and $F$ are to go to a field; select either motor, it does not make any difference which one, and connect the $A$ leads to its armature and the $E$ and $F$ leads to its two field terminals; then go to one controller, throw the reverse switch ahead and start the car. If she starts ahead, all right; if she starts back, it is only necessary to reverse either the field or the armature leads, but not both.

One motor is now connected; the next step is to connect the second motor just like it, only either the field or armature leads must be reversed; i. e., if the $F$ field cable lead went into the top field on the first motor connected, it must also go into the top field on the last one, but if the $AA_1$ cable lead went to the head brush terminal on the first motor, the $AA_2$ cable lead must go to the rear brush on the last motor connected. The result of this hit-and-miss method of connecting the motors may be to get them connected in a way never shown on a blueprint, but, if all the cars on the road are connected in the same way, no harm is done.

**35.** If, in Fig. 18, the field connections on both motors are reversed, the car will run all right, but will disobey the reverse-handle indications on both ends. The matter can be made right by putting the field leads back the way they were, or by reversing the armature leads. Connections can be also very much mixed up and still run the car right by juggling the armature and field wires in the controllers. As

a matter of fact, it does not make much difference how the field or armature wires on a car get mixed up among themselves, provided they do not get mixed up with each other, and the car obeys the indication of the reverse switch on both ends. On the other hand, it is possible, when connecting up both motors and controllers for the first time without the aid of a blueprint, to get the field leads so very badly confused with one another and the armature leads also confused, both at the motors and in the controllers, that very little can be done in the way of running the car.

**36.** A series of tests will cause symptoms to show up that will readily tell what is the matter with the armature and field connections. Let us suppose that we have just finished the wiring of a car and that the car must be tried to see if the connections are right. In testing out a car for the first time after connecting it up, some men prefer to cut out one motor and try the motors one at a time. Others prefer to try them both cut in first. Neither way has any particular advantage. Assuming that all other connections are right and considering only the possible confusion of field or armature leads, if the car fails to start on the first or second notch, it means that the motors are so connected as to oppose each other; i. e., try to run the car in opposite directions. In such a case, the cut-outs must be used, and the motors tried one at a time from both controllers.

If one motor obeys the reverse handle on both ends, its circuit is all right and should be let alone. If the other motor disobeys the reverse handle from both ends, its field or armature connections must be reversed at the motor itself, but if it obeys the reverse at one end and disobeys it at the other, the fault is in the controller at that end, and the field or armature wires must be reversed in that controller. If the car starts all right with both motors cut in, but disobeys the reverse switch at both ends, it means that the field or armature on both motors must be reversed to right matters. If both motors obey the reverse on one end, but disobey it on the other, the fault is in the controller and must be fixed by

reversing there a field or an armature on both motors. This about covers any confusion liable to take place in a field or armature circuit.

**37. Troubles.**—The troubles that motormen meet with are almost always caused by open circuits or grounds, and a car's action under such a condition depends entirely on where the fault may occur. It sometimes happens that the trolley connecting post or the trolley finger, the top one on the power-drum finger board, the rheostat casting on the drum, the starting coil itself or some wire running to it becomes grounded. By looking at Fig. 18, it can be seen that the effect of a ground in any of these places could not be removed by using the cut-out switches, because each cut-out can only look after that section of the circuit which is included between the points where the current enters its own motor and leaves it.

Cut-out switch No. 1 can, if it is thrown up, remove the effect of any ground that may take place between lower block *19* and lower block $E_1$, since lower block *19* is the point where the current starts for the No. 1 motor by way of the reverse switch, and lower block $E_1$ is the point where the current returns from the No. 1 motor after passing through its field, armature, and parts of the reverse switch and connecting board. If the No. 1 cut-out switch be thrown up, these two blocks, and with them the whole No. 1 motor circuit, are left without any connection so that the fault can have no effect on the rest of the circuit. Motor cut-out switch No. 2 is able to do away with the effect of any ground that may occur beyond lower block *15*, because as soon as the switch is thrown up, the current is given another path to the ground through ground block *G*.

**38.** That part of the circuit which is included between top block $E_1$ and top block *15*, Fig. 18, cannot be cut out by either of the cut-out switches. Suppose a ground to take place on upper finger $E_1$, and suppose, for example, that both cut-out switches are thrown up. It must be borne in

mind that the current is trying to get to the ground by way of the shortest path it can find, and, further, that not only is the controller frame grounded to the dash rail and thence through the brake staff, chain, road, and shoes to the wheel, but the ground block $G$ is purposely connected to the controller frame in order to prevent certain parts of the controller from getting charged should the insulation get weak. The result of having the frame grounded is, that as soon as a weak spot shows up in the controller insulation, the current has a good path through which to jump to earth.

With both cut-out switches up and no ground at $E_1$, the path of the current would be, on the first notch, $T$–$M$–$T$–$K$ –$K_1$–$R_1$, around through all the starting coil and back on the $R_4$ car wire to point $X$, where it splices on to the No. 19 wire, which runs to the upper *19* block on the cut-out switch; from this point, the path is $SS$–$E_1$–$E_1$–*3*–*2*–*1*–*15*–*15*, and right to earth through block $G$. With a ground on finger $E_1$, the current would get no further than that finger, and it would be so large, especially if the controller handle were advanced a couple of notches, that fingers $T$ and $R_1$ would be melted in trying to break so large a current.

In case of a ground on the rheostat drum casting, the current would get no further along this route than this casting, from which it would pass through the fault to the shaft, down and up the shaft to the frame, thence through the brake rigging to the earth. Only the trolley fingers would be in circuit to break the arc, which would be enormous because, since the fault is ahead of the starting coil, none of its resistance would be in circuit to place any limit to the current value.

It is such grounds as these that blow holes through the controller door and singe the motorman's trousers. Now a ground anywhere between $K$, $K_1$, etc. and top block *19* or between top blocks $E_1$ and *15* would not show itself until the power drum were put on the first notch, because this has to be done before any communication is established between the fault and the trolley finger $T$. If such a fault occurs while the car is in motion, the controller usually gives a

display known as "blowing up," which generally frightens front-end passengers to the point of jumping off, and loads the company down with damage suits. Now a great many of these "blow-ups" of controllers are caused by rough handling, so the moral to be drawn from this fact is, "Treat a controller as if it were your own."

**39.** The faults that have just been considered are in a class by themselves, in that they cannot be cut out by means of the motor cut-out switches and in that they do not show up until the power drum leaves the off-position and brings into service the trolley finger on the power-drum board. Now there is another class of grounds more difficult to deal with; these are grounds that take place between block *T* on the connecting board and finger *T* on the power-drum finger board. If two controllers are used, a car wire runs the full length of the car from block *T* on the board of one controller to block *T* on the board of the other controller and the trunk wire from the kicking coil splices on to this car wire somewhere in the course of its length.

Since the trolley blocks and fingers of the two controllers are thus connected, a ground on one controller will make it impossible to use the other until the ground is removed or cut out of the circuit; further, the ground will show itself as soon as the pole is on and both hood switches are in. If the car is in motion, the fault is as apt to take place when the power drum is off as when it is on; the circuit in both controllers is always alive up to top trolley finger *T* whether the power drum is on or not, as the power drum is simply a means of leading the current to the two motors.

As a matter of fact, grounds very seldom take place in the connections between block *T* and finger *T*, but they sometimes do, and they are most always due to grounding of the blow-out magnet coil *M*. In such cases, more or less flame and smoke generally accompany the development of the fault and serve to show in which controller the fault is. To do away with the fault, it is only necessary to remove the car wire running into block *T*. This makes the controller

dead so that it can give no further trouble and the car can be run in from the rear end. Of course, a ground on the fuse box, lightning arrester, kicking coil, or trunk trolley wire will render the car useless until the fault is removed, and the symptoms will be about the same as if the fault were in the blow-out connections *T*, *M*, *T*, only the smoke and fire are apt to be under the car, where only an inspection can locate the trouble.

It seems to be a very common practice among motormen, as soon as they find one controller will not work on account of being grounded, to go to the other end of the car and blow up that controller too. If a man finds that one of his controllers is grounded in such a way that the motor cut-outs are of no use, he should, before trying the second controller, disconnect the trolley wire of the first one. Also, if it has been found necessary to cut out one motor on account of trouble, the motorman should bear in mind that before using the other controller, the same motor should be cut out in it too. This precaution very often saves burning the controller fingers and drum tips.

**40. Open Circuits in Wiring.**—The points where the main-trunk trolley wire is apt to be broken have already been enumerated, and at this point the usual method of deciding if the break is in this part of the circuit or elsewhere will be given. The student must be warned once more that, before deciding that the failure of a car to start on the series notches is due to any fault in the circuit, he must be certain that the pole is on the wire, that both hood switches are in, that the main-motor fuse is intact, that the rail is not dead, and that there is power on the line. This being done, the test for other troubles is in order.

**41.** If a car that ordinarily starts on the first notch unexpectedly fails to do so, advance the controller handle to the fourth notch, but do it one notch at a time, just as in service; if the car starts on the second notch, it indicates one of three conditions: the $R_1$ finger does not make contact with drum

tip $K_1$; the starting coil itself is open-circuited between $R_1$ and $R_2$; the $R_1$ car wire is open-circuited or the controller wire running from block $R_1$ to finger $R_1$ is open-circuited. If the car starts on the third notch, it indicates an open circuit in the starting coil between $R_1$ and $R_3$. Such a symptom might possibly be due to both fingers $R_1$ and $R_2$ failing to make contact or to open circuits in both the $R_1$ and $R_2$ resistance wires, but such a condition is not very apt to occur. If the car fails to start until the fourth notch is reached, where the starting coil is entirely cut out, the symptoms point to an open circuit in the starting coil between $R_3$ and $R_4$.

If all the resistance wires were pulled out of the controller, except the $R_4$ wire, the car would act in just this way; but such a condition is not apt to arise except where a car has been run over a pit for repair or test and the wiremen have neglected to reconnect the resistance wires. If the car starts on the first notch, but loses the power on the second notch, and picks it up again on the third notch, a sizzling noise will be heard inside of the controller; this means either the $R_2$ finger is not making good contact or that the $R_2$ resistance wire is open-circuited somewhere in its course through the controller or underneath the car. If the car loses the power on the third notch, there is something the matter with the $R_3$ resistance-wire circuit or with the $R_3$ finger.

A complete loss of power on the fourth notch indicates that the wire running from splice $X$ to top block *19* is open, but if there is only a partial loss of power, with the car running at about the same speed as on the second notch, it means that either finger $R_4$ makes no contact or that controller wire $R_4$, *19*, $X$ is open-circuited, in which case the current goes to the starting coil through the $R_2$ finger and the No. 2 resistance wire, thereby introducing the same resistance that was in circuit on the second notch.

If the controller resistance wire $R_4$, $X$ has an open circuit in it, the car cannot start until the fourth notch is reached; a break in $R_4$, $X$, therefore, causes exactly the

same symptoms as an open circuit in the starting coil itself bewteen $R_3$ and $R_4$.

**42.** So far, so good, for a car that has but one controller; but where there are two controllers, an open circuit, in most cases, occurs in such a way as to affect the operation of one controller without in the least way affecting that of the other. Take notice that in the wiring diagram, Fig. 18, certain parts of the circuit carry current, no matter which controller is in use, but there are other parts of the circuit that are not common to both controllers and therefore carry current only when that controller with which they are identified is in use. As an example, the motors, resistances, shunts, and the short wires leading from them are in connection to both of the controllers and therefore carry a current when either controller is used; but in the case of the hose wires running the full length of the car from one controller to the other, at no time does any of these wires carry a current throughout its length. The splice from the motor, shunt, or resistances, as the case may be, is the point from which or to which the current for that device is led. For example, on the first notch, the current leaves the drum on finger $R_1$ and travels along the $R_1$ controller resistance wire to connecting-board block $R_1$, out of which it passes by way of car-hose resistance wire $R_1$ to the No. 1 end of the starting coil; passing through the starting coil, it leaves by way of a lead that splices on to the $R_4$ car-hose resistance wire, and thence back to the connecting-board block $R_4$ and on to the splice at $X$.

Now, had the No. 2 controller, to which the broken-ended car wires lead, been in use, only that part of the car wires which is on the right hand of the splices would carry any current. The result of all this is as follows: an open circuit in any device or wire that is common to both controller circuits will affect both controllers. As an example, suppose the car fails to start on the first notch on both controllers and starts on the second notch on both; this means that either the starting coil itself is open between $R_1$ and $R_2$, or

that the $R_1$ resistance splice on to the car wire $R_1$ has broken or come loose. If on one controller the car starts on the first notch, and on the No. 2 controller it does not, it means that the path from the $R_1$ finger on the No. 2 controller to the $R_1$ splice on the starting coil is open either in the controller itself or in the car wire that leads from the $R_1$ connecting-board block to the splice.

It is always a good plan, then, to try both controllers, so as to decide if the trouble is in the controller itself or in some wire or device common to both controller circuits. If an open circuit occurs of such a nature that the car will not move on the first, second, third, or fourth notches on either of the controllers, it indicates an open circuit in one of the motors or in some wire leading to it.

**43. Open Circuit in a Motor.**—Ordinarily, it is the practice among motormen, if the car refuses to start on the first four notches, to push the controller handle on around until the car does start. If the trouble is an open circuit in one of the motor fields or its connections, the car is apt to start on the fifth notch, because, although the open field opens the whole circuit, the two motors being in series on the first four notches, as soon as the fifth notch is reached, the shunt on the faulty motor comes into action, and, bridging over the open-circuited field, allows the current to pass through the shunt to the good motor, which is thereby enabled to start the car. The proof that such a condition of affairs exists is, that the shunt on the faulty motor gets very hot and gives off an odor, which, once experienced, is readily identified ever after. As soon as the handle is moved past the fifth notch, the shunt tip *2* or *5*, as the case happens to be, passes out of action, and, being obliged to break the whole circuit, burns badly on the inside. If the No. 1 motor has the open-circuited field, the fifth notch will start the car on the No. 2 motor; if the No. 2 motor has the open-circuited field, the fifth notch will start the car on the No. 1 motor.

If one motor has an open-circuited field, it is a very bad

idea to move the controller handle on around to the ninth notch, because there the shunts come into action again. Since the motors are in multiple and their circuits independent, the result is that the shunt on the faulty motor, being thrown directly across the line, is apt to be burned up before the main-motor fuse can blow and save it. An old motorman in making the passage from series to parallel can tell which motor is open-circuited by noting the position of the handle when the car again takes the power. The No. 1 motor is dropped on the sixth position and is picked up on the seventh. The No. 2 motor is not picked up until the ninth position is reached. The best way to decide which motor is open-circuited is to cut them out one at a time and try the car. If the car starts when the No. 1 switch is down, and the No. 2 switch is up, the No. 1 motor is the good one.

**44. Open Circuit in the Shunt.**—An open circuit in the shunt on a car that has two motors is not as readily noticed as it is on a car that has only one motor, for the change in the speed is not so great. The effect of an open-circuited shunt on one motor is to make the other motor take more than its share of the load on the fifth and ninth notches, because the motor whose field is shunted has less counter E. M. F. in its armature than has the motor whose shunt is not in action, and therefore offers less opposition to the line voltage sending current through it. The armature of the good motor runs hotter than that of the bad one, but the field of the faulty motor is apt to get the warmer of the two, because it no longer has a shunt to relieve it of a part of the current.

A car should be regularly inspected to insure that both shunts are in working order. This inspection consists in opening the controller door, advancing the power handle to the fifth notch and then in throwing the drum to the fourth notch again to observe if there is a slight arc on the $L_1$ and $L_2$ fingers. If one of these fingers should fail to show a slight arc, due to the interruption of the small current that

the shunt circuit carries, it indicates an open circuit in the shunt or in some of its connections.

**45. Open Circuit in Armature.**—As an open circuit in the armature is a fault common to all styles of equipment whatever type of control may be in use, its consideration will be taken up later when troubles in general are dealt with.

**46. Grounds.**—The way in which a car will act when some part of its wiring or some device is grounded depends a great deal on where the ground is. As has been said before, a ground anywhere on the circuit in between the trolley wheel and the positive side of the fuse box will have to be removed before the car can be operated; as the main-motor fuse is not in circuit with such a fault, some part of the car wiring is apt to blow instead, unless the circuit-breaker at the power house relieves the situation.

A ground anywhere between the negative side of the fuse box and point *O*, where the wire from the kicking coil splices on to the car wire that runs the full length of the car from the *T* connecting-board block in one controller to the *T* connecting-board block in the other controller, will, of course, blow the main-motor fuse, and, since it is on a wire common to both controller circuits, it must be removed before the car can be operated from either end. Such a ground as this is due, as a rule, to one of two causes: either the lightning arrester has become short-circuited during a discharge, or the main trolley wire (especially on double-truck cars whose trucks swing out a great deal when rounding curves) has come in contact with some part of the motor or of the brake rigging.

If the ground takes place in the controller itself between block *T* and finger *T*, it will, of course, be impossible to move the car until the ground is removed. Since this part of the circuit belongs to the No. 1 controller, its effect on the No. 2 controller can be done away with by disconnecting the trolley wire from block *T*. The wire must be bent back far

enough to insure that it cannot be jolted up against the frame back or some other connection, but must not be bent so far that the controller door, when it is closed, will touch it. Grounds of this sort do not often take place in the type K controllers, because they are so well protected, but they take place sometimes, and, when they do, are generally due to the breaking down of the insulation in the winding of the magnetic blow-out coil, this in turn being generally due to abuse or neglect.

**47.** A ground on the rheostat casting $K_1$, $K_2$, $MK_4$, etc., Fig. 18, has no effect until the power drum is put on the first notch; so that as long as the No. 1 controller is left on the off-position, the ground cannot interfere with running the car by means of the No. 2 controller. A ground anywhere on the drum, as a rule, burns it so that it has to be taken out and repaired. A ground on the $R_1$ finger or anywhere between this finger and the $R_1$ post on the starting coil, will blow the main-motor fuse as soon as the power drum is put on the first notch.

Only an inspection will tell whether the ground is on the finger, the starting coil, or on some wire or connection between them. A ground on any of the resistance fingers, on finger *19*, or on the starting coil itself, or on any wire that runs to them, will show itself as soon as the power drum is put on the first notch, because all these fingers are connected together, all being connected to the starting coil; but the violence with which the ground shows itself on the first notch depends entirely on which part of the circuit is affected. Suppose the fault to be on the fourth post of the starting coil, on the $R_4$ connecting-board block, or on the $R_4$ or *19* power-drum fingers; in any of these cases, on the first notch, the current would have to pass through the whole of the starting coil before it could reach the ground through the fault. The main-motor fuse would, therefore, probably not blow with the drum on the first notch, but would blow if the drum were advanced to the second or third notch.

The distance that the controller handle would have to be advanced to blow the main-motor fuse would depend a great deal on the condition of the starting coil—whether it were new or old, cold or hot. A very old coil would be apt to allow the fuse to blow on the first notch, on account of its resistance being so low; it is such coils as these that allow a car to start with a jerk. Also, the voltage on the line has a great deal to do with the action of the car. On the same system, the line voltage may be 550 volts in one place and 350 in another place, and, of course, 350 volts line pressure would not be nearly so apt to blow the main-motor fuse on the first notch as would a line pressure of 550 volts.

**48.** In case of a ground on lower cut-out block *19*, reverse finger *19*, on the wire connecting the two, or on any tip on the reverse drum engaged by the finger *19*, the symptoms would be the same; i. e., the car would not move and the main-motor fuse would blow as soon as sufficient resistance were cut out of the starting coil to permit it. A ground here differs in one respect from those just considered, in that it can be removed in effect by throwing up the No. 1 motor cut-out switch.

A ground on finger $A_1$, block $A_1$, the motor brush to which the $A_1$ car wire runs, or on any connecting wire, gives the same symptoms as in the last case, and can be cut out by means of the No. 1 motor cut-out switches, but it has the further characteristic that, although it will not allow the car to be run ahead, being on the positive side of the motor, it will, under certain conditions, allow the No. 2 motor to become a generator and cause the speed of the car to be violently checked. The conditions are that the car should be under good headway, that the main-motor fuse blow, and that the reverse handle be thrown back. It is necessary that the ground occur while the car is in motion, because, of course, the armature cannot generate unless it is turning. It is not necessary that the main-motor fuse should blow, but it always does, thereby cutting off all connection between the motors and the line. It is necessary that the reverse

switch be thrown before the No. 2 motor can generate a current of its own, because, as has been stated in Art. **30,** *Car Equipment*, Part 5, when a series machine is connected up to run in a certain direction as a motor, it cannot be made to generate unless either the direction of rotation is reversed or its field or armature connections reversed. In the case in question, the direction of rotation is fixed so that, in order to make the motor generate, either its field or armature must be reversed. On the K2 controller, the effect of throwing the reverse switch is to reverse the armature connections on both motors.

In Fig. 20, $G$ is the place where the ground is supposed to take place; $G'$ is the place where the ground is shifted to, as soon as the reverse switch is thrown; and $G''$ is the regular ground wire through which the current ordinarily reaches the rail when both motors are in good order. Suppose both motors to be in good order, the car under good headway, the pole off and the reverse switch thrown back.

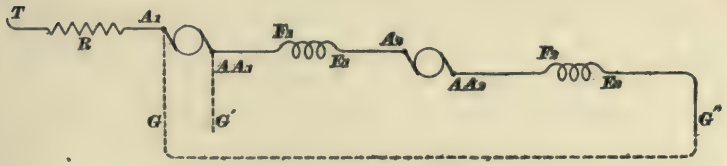



FIG. 20.

If a wire connected to the positive side of the No. 1 armature or its connecting-board block or finger be touched to one of the motor frames or to the truck, the car will be suddenly halted. The reason is that both machines are connected up as generators and their circuit is completed through the experimental ground wire and the regular motor ground wire, as indicated by the long dotted line in Fig. 20. Now, in the case in question, the No. 1 machine cannot generate because the throwing of the reverse switch puts the fault between the armature and the field, thereby cutting the armature out of the local circuit in which the dynamo action takes place. The No. 2 motor only has a complete

circuit through both armature and fields and alone generates.

**49.** A ground between field lead $E_1$ on motor No. 1, Fig. 18, and armature lead $AA_2$ on motor No. 2 has one peculiarity. Beginning at $E_1$, the following part of the circuit is included: $E_1$–$E_1$–$E_1$–$E_1$–$E_1$–3–2–1–15–15–15–15–$A_2$–$A_2$ –$AA_2$, and this corresponds to the part $E_1$–$AA_2$ in Fig. 21. If the fault takes place while the car is standing still, its effect is not apt to be noticed until the power drum is thrown to multiple, because there is no violent demonstration of any kind. True, the car starts more slowly, but only an old motorman would notice this and he would not know but that the slow start was due to low voltage on the line or to a bad rail. The reason the ground does not announce itself until the power drum is thrown to multiple is that, as long as the motors are in series, the fault has no bad effect other than to cut out the motor nearest to the ground.

In Fig. 21, $G$ is the regular ground and $G'$ is the fault; ordinarily, the current takes the path $T$–$A_1$–$AA_1$–$F_1$–$E_1$–$A_2$ –$AA_2$–$F_2$–$E_2$–$G$; but if the fault takes place at $G'$, the current takes the short path $T$–$A_1$–$AA_1$–$F_1$–$E_1$, and to the earth through the fault at $G'$, thereby cutting out the No. 2 motor. As soon as the power drum is thrown to multiple, the fault no longer has the counter E. M. F. of the No. 1 motor ahead

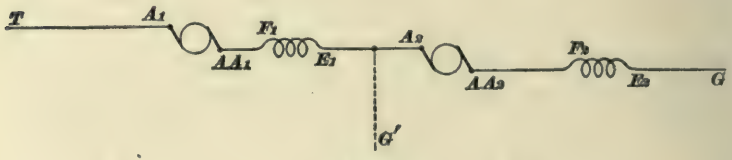



FIG. 21.

of it, and so the main-motor fuse blows. If such a fault takes place while the car is in motion, and the motors are in series, the only effect is to make the car jump ahead because cutting out one motor and its counter E. M. F., thereby throwing the whole line voltage across the remaining motor, is, in effect, about the same as cutting out just so much resistance.

As a matter of fact, if a car were equipped with four street-car motors so wired that at the start all four of the motors were in series, a very small starting coil would be required and several degrees of speed obtained by cutting out the motors one at a time and then cutting them in again in multiple instead of in series. If the fault takes place while the power drum is in multiple, there is, of course, the usual display of fireworks in the controller and the main-motor fuse blows.

**50.** A ground on the No. 1 motor shunt acts the same as a ground on the $F_1$ field wire, and a ground on the No. 2 motor shunt acts the same as a ground on the $F_2$ field wire. A ground on power-drum shunt casting *2*, which is the same casting as *3* and *1*, would act the same as a ground on finger *15*, but a ground on power-drum shunt casting *4* and *5* would not be felt until the fifth notch were reached and would then not be apt to give any demonstration other than burning or smoking in the controller, because $L_2$ is intended to be grounded on that notch.

**51.** The discussion that has just been ended regarding the K2 controller covers most of the faults liable to happen to the controller and gives the student some idea of how to follow out car-wiring diagrams for himself and explain many peculiar things that are otherwise often hard to see.

---

### THE K11 CONTROLLER.

**52.** Fig. 22 gives the appearance of the K11 controller. This controller is a great deal like the K2, but has two distinguishing features. Its contacts are of larger current capacity, the controller being designed for use with 50-horsepower motors, whereas the K2 controller is intended for use with 35-horsepower motors. The K11 controller is also intended to be used with motors that do not require a shunt. The K2 controller can handle motors with or without the shunt, the shunt wires being simply left out where no shunts

are used, but on the K11 controller there are no shunt fingers or connecting-board blocks provided, so that a shunt cannot

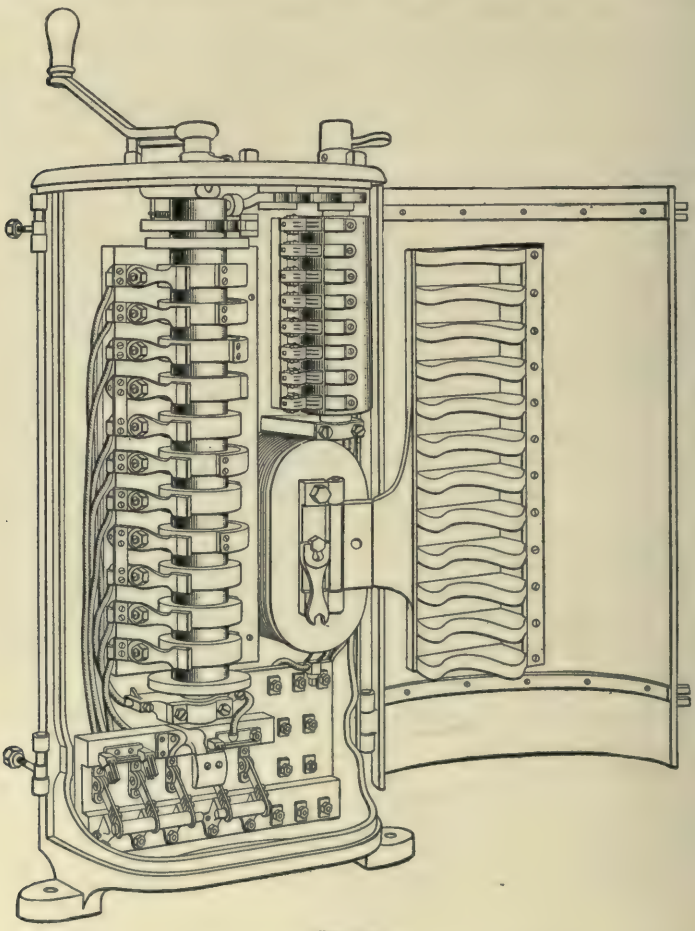


FIG. 22.

be used unless both ends of it are permanently spliced on to the two field terminals.

**53.** Fig. 23 gives the combinations effected on all positions of the power drum. There are five notches in series and four notches in multiple, making a total of nine notches,

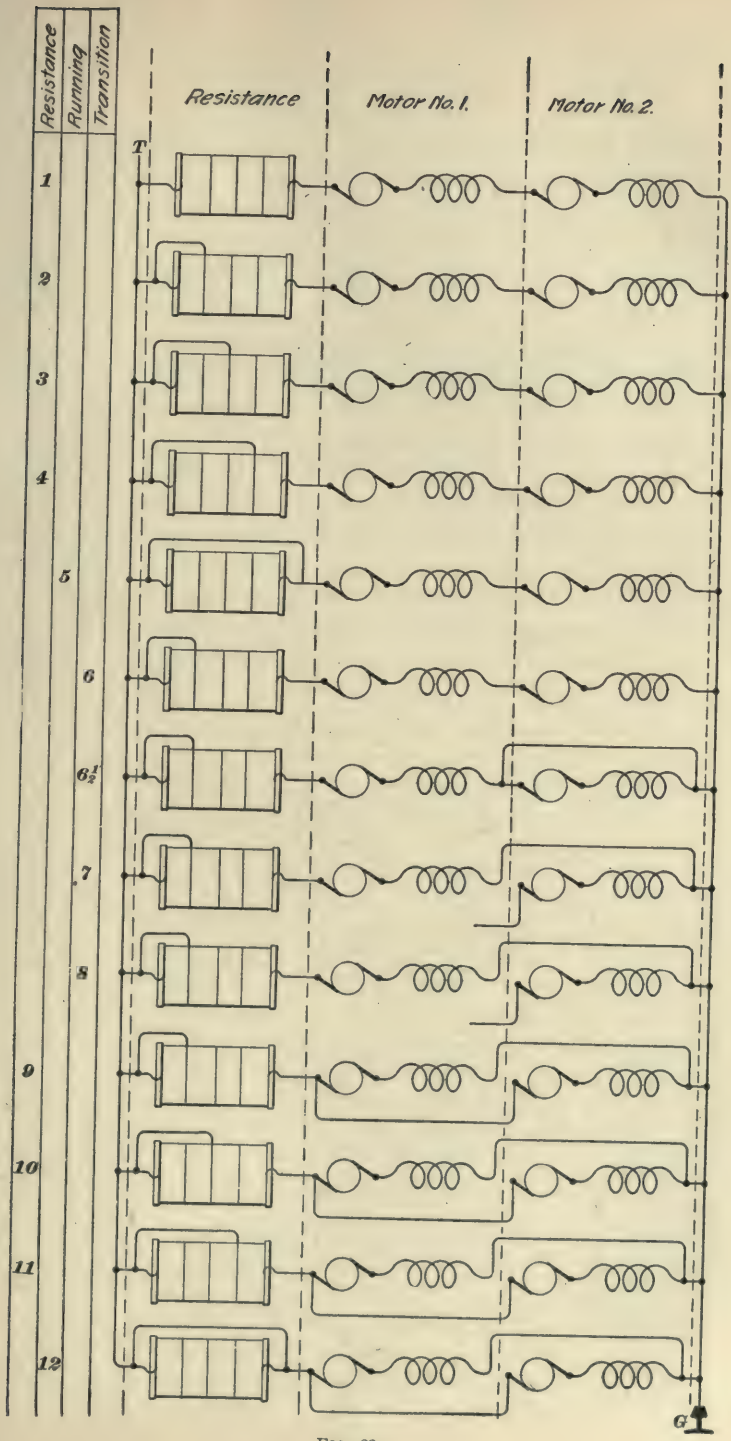

Resistance
Running
Transition
Resistance
Motor No. 1.
Motor No. 2.
T
G
1
2
3
4
5
6
6½
7
8
9
10
11
12

FIG. 23.

the same as on the K2 controller. But whereas the K2 controller had four running notches, two in series and two in multiple, the K11 has only two running notches, one in series and one in multiple. When there are both K2 and K11 controllers in use on the same road, a confusion in handling is apt to arise, with the result that, on all cars equipped with the K11 controllers, the starting coils give a great deal of trouble. This is more apt to be the case if the men use the K2 controller first, for the following reason: When a man becomes acquainted with the handling of the K2 controller, he has become accustomed to using the fourth, fifth, eighth, and ninth notches as running notches, which, of course, is perfectly proper; but on the K11 controller, the fifth and ninth notches only are running notches, the fourth and eighth notches being resistance notches, which include in circuit the last panel of the starting coil. The result of this is that a man is running on resistance half the time and does not know it, and the resistance will not stand it, nor is it intended to. In Fig. 23 the numbers refer to the various positions. Positions *5* and *12* are running positions and correspond to the fifth and ninth notches.

No man can change from one car to another several times a day, perhaps getting a different type of controller each time, and bear in mind the fact of there being a difference, when the two controllers are so much alike that most men have to look on the name plate to tell which type it is. It will be seen, upon looking at the notch diagrams, that the starting coil used on the K11 controller has one more part in it than has the starting coil used with the K2. The K11 connecting board has, therefore, one more resistance block than has that of the K2. There is also one more power-drum resistance finger, but, altogether, the K11 has one less power-drum finger than the K2. This is accounted for by the fact that, on the K11 controller, the two shunt fingers have been left out and but one additional resistance finger has been put on. The K11 controller has eleven power-drum fingers and the K2 has twelve.

# CAR EQUIPMENT.

(PART 8.)

## WESTINGHOUSE EQUIPMENT.

### WESTINGHOUSE MOTORS.

#### WESTINGHOUSE NO. 3 MOTOR.

**1.** In taking up the street-car motors made by the Westinghouse Company, the subject would not be complete were no place given to the **No. 3 motor,** for it is upon the record made by these motors that the Westinghouse Company based their first claims to recognition as motor builders, and the company have never departed very widely from the good lines to be found on the No. 3 motor.

Fig. 1 shows the No. 3 motor as it appears with the upper half thrown back. In this figure, $P, P$ are the pole pieces cast as a part of the top field shell $K$; the two lower pole pieces are cast as part of the lower shell, not shown. $F$ is the frame or yoke to which the top and bottom field shells are hinged, as shown in Fig. 2. $A$ is the armature; $E, E$, the two top field coils; and $S, S$, the two brass shields that slip over the pole pieces, and by means of bolts in each of their four corners hold the field coils in place against the motor shells. $D, D$ are dust guards made of sheet iron. They are secured to the sides of the motor shells by means



For notice of the copyright, see page immediately following the title page.

of capscrews, and while they do not make the motor dust-proof or waterproof, they do protect it a great deal. As a matter of fact, there are records to show that in many cases where the No. 3 motor has been in service alongside some of its more up-to-date rivals, it has actually held its own against the snow, sleet, and slush better than its rivals. This is due to the fact that the more up-to-date motors are so

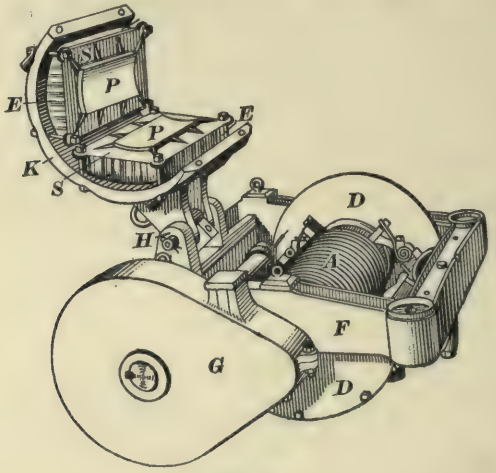



FIG. 1.

effectually closed that the salt and water once inside of them could not get out, whereas, on the No. 3 motor, with its well glazed field-coil surface, the water would not stay inside long enough to do any harm. It is probably safe to say that the No. 3 motor was never replaced because there was any crying need for a better motor, but because its limited output made it unable to meet the demand for higher speeds on heavier cars. High speed and large cars are what are called for today.

**2.** Fig. 2 is not drawn to scale, nor is it an actual reproduction of the parts to be considered, but it will serve to give a fair idea as to how the top and bottom motor shells are hinged to the frame *F F*, and how this frame supports the armature. The frame *F F* has two sets of lugs *H'*, *H'*

cast on either side; the lugs *H*, *H* on the top and bottom motor shells pass between the frame lugs, and a pin passing through the three lugs forms a hinge upon which the shells work when they are raised or lowered; dotted lines *b b*, *b b* show where long motor bolts pass through the two shells to hold them snugly together. There are four of these bolts. On the lower side of frame *F F*, the armature *A* is hung by means of cap *c* secured with bolts *d d*, *d d*. From Figs. 2 and 3 it can be seen that the armature and two shells are hung entirely independently of each other, and that the top shell can be raised or the bottom shell lowered without in any way disturbing the armature. To raise the top shell, in order to get at a field coil, bolts *b b*, *b b*, Fig. 2, are taken out and the shell can ordinarily be thrown back by hand; but sometimes this cannot be done, because the hinge pins are, in the first place, made such a snug fit in the hinge lugs *H*, *H'*, *H*, *H'*, that if allowed to remain undisturbed for a long time, they rust together so as to resist turning. In such cases, it is customary to pour kerosene on the hinge and hammer the pin back and forth with a sledge. If the hinge refuses to yield, the only thing to do is to take the motor off the truck and drill the pin out, as any determined effort to move the pin with a sledge is apt to result in breaking off some of the lugs. This method of raising a shell may strike the student as involving a great deal of work, and so it does; but if a motor runs so long without trouble that some of its parts rust together, it ought to be a very good motor, and the owner should be well satisfied.

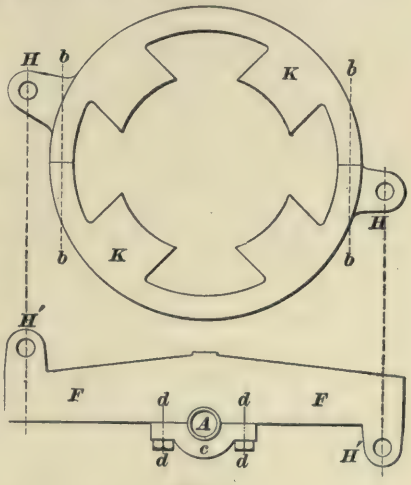



FIG. 2.

The pins are made a snug fit in the hinges so that there will be no motion to cause wear and thereby let the pole pieces down on the armature. It must be borne in mind that the shells are bolted together and as a whole are swung independently of the armature; they are so hung and bored that when the armature is snug up into its position, every pole piece is at the same distance from the core. Now any wear in either hinge pin will let both shells down out of center and thereby bring the top pole pieces nearer to the core, and the bottom pole pieces farther from the core than they ought to be. If this wear is allowed to keep on unnoticed, it will be only a matter of time when one of the pole pieces is down on the armature, rubbing off a band. Aside from this, as soon as the armature gets farther away from one set of pole pieces than it is from the other set, the lines of force become unevenly distributed and are apt to cause sparking. Fig. 3 shows how the field is mounted in the yoke *F*.

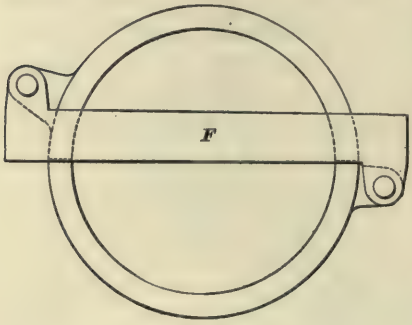


FIG. 3.

**3. How to Handle a No. 3 Motor in the Pit.**—If it is desired to take out a bottom field from below, it is best to do so with the aid of a **pit jack.** A pit jack is an ordinary pump jack, swiveled to the table of a four-wheel truck so that the jack can be freely turned about. The rack is made extra long to suit existing conditions, and is fitted on top with a padded or roller cradle, which is able to handle an armature without bruising the heads or the band wires. The jack is pumped up under the motor shell until some of the weight of the motor is taken off the suspension springs; bolts *b b*, *b b* are then taken out, when the bottom shell should be free to lower as the jack is pumped down. If it refuses to

come on account of binding in the hinge pins, try to pinch it down with a crowbar; if this fails, tie one end of a chain or a good stout rope to the motor shell and the other end to one of the pit posts or any other conveniently disposed anchor, and start the car on the remaining motor, in such a direction as will tend to open the shell. This treatment will generally move it. If it does not, the only thing to do is to lift the motor off the truck and drill the pin out.

To take out an armature, the lower shell must be let down by means of the pit jack, the jack then removed, and the rack run up under the armature until the weight is taken off the caps that support it; the bolts are then taken out of the caps (one cap is on the commutator end, the other on the pinion end) and the armature can be let down on the jack.

If a top field must be replaced and it is not possible to raise the top shell on account of the construction of the car, or it is not convenient to run the truck out from the car body, the lower shell must be dropped and the armature taken out before either top field can be reached. The above instructions have been given under the assumption that a pit jack is at hand, but more often than not, such is not the case. The job can be done with no other conveniences than a board about 12 feet long, a rope, and plenty of good blocking. To lower the bottom shell with this rigging, one end of the rope is tied to an eyebolt in the bottom shell; the other end must be passed up into the car, drawn tight to take off as much weight as possible, wound several times round a piece of timber laid across the trap, and the other end secured so that the rope cannot slip; the four motor bolts are then taken out and the shell let down gradually by allowing the rope to slip round the piece of timber.

To remove an armature, block it up as shown in Fig. 4. Different conditions might change the disposal of the blocking somewhat, but Fig. 4 shows a general method that ought to cover average conditions. In Fig. 4, *A* is the armature; *B*, *B*, *B*, the blocking; *c*, a block that is wedge-shaped on one end to help control the rolling of the armature down plank *d*. Plank *F* is placed across the pit, and plank *e* runs from it

down to plank *d*, so that the armature can be rolled up on to the floor without rolling it into the bottom of the pit, from where it will only have to be lifted again. With the aid of

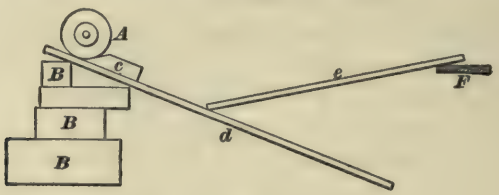



FIG. 4.

a pit jack, one man can handle the No. 3 armature, but without it, it takes two men.

**4. Bearings.**—The bearings on the No. 3 armature are malleable iron sleeves babbitted to fit the shaft. These bearings are unusually small in diameter for a motor of 25 horsepower, but give no trouble. The commutator end is 5 inches long by $1\frac{3}{4}$ inches in diameter, and the pinion end is $5\frac{3}{4}$ inches long by $2\frac{1}{2}$ inches in diameter.

**5. Armature and Commutator.**—The armature is of the usual slotted type, and can either be hand wound or wound with coils as all up-to-date armatures are. Unlike most other types of street-car armatures, the length of the armature is greater than the diameter. There are 95 slots in the armature core and 95 bars in the commutator; there are as many coils as slots, so that each slot holds one side of two coils. On some roads, each coil has four turns of wire in it, and on other roads each coil has three turns. In many places, the demand for more speed has made the change from four turns to three necessary, but in doing this it has always been the rule to increase the size of the wire at the same time, because a three-turn armature takes more current than does a four-turn armature. By choosing suitable insulation, the No. 3 armature can be wound with No. 9, No. 10, or No. 11 B. & S. gauge, double cotton-covered wire. The four-turn armatures, as a rule, are wound with a No. 11 B. & S.

wire, and the three-turn with a No. 10, or between No. 10 and No. 9.

**6. Armature Connection.**—There is nothing peculiar about the armature connection on a No. 3 armature that is not peculiar to the armature connections on all motors of this type; i. e., to all motors that have their pole pieces on the diagonal. The G. E. 800, it has been noticed, has two field coils, one on the top and one on the bottom, so that a straight line drawn through the centers of any two diametrically opposite pole pieces and the center of the circle representing the armature, coincide with a horizontal and a vertical line drawn through the center of the armature. On the G. E. 1,000, the G. E. 57, the Westinghouse No. 3, and most of the motors to be described hereafter, the two straight lines drawn through the centers of diametrically opposite pole pieces make an angle of 45 degrees with the horizontal and vertical lines; in other words, on such motors as the G. E. 800, the pole pieces might be said to be on the north, east, south, and west sides of the armature, whereas all other four-pole motors have their pole pieces on the northeast, southeast, southwest, and northwest sides of the armature.

It has been learned elsewhere that the brushes on a dynamo or motor are always so placed on the commutator that the bars passing under the brushes are connected to coils that are not generating any E. M. F. These coils are passing through what is called the **neutral field.** The center of the neutral field is called the **neutral point,** and the straight line joining any two diametrically opposite neutral points is called the **neutral line.** The neutral points are always midway between the horns of adjacent pole pieces, and the brushes are always found midway between the horns of the pole pieces, unless for some good reason they must be placed elsewhere.

On the No. 3 motor, and on all motors of the same type, the brushes are found to be opposite the centers of the pole pieces.

Fig. 5 (*a*) represents a motor whose pole pieces are situated

in the same way as those of the G. E. 800. The brushes *b*, *b*, *b*, *b* are midway between the pole pieces, where the direction of the lines of force is such that the wires in the slots slide along them and do not, therefore, cut them; the brushes *b*, *b*, *b*, *b* are in the neutral points, and the dotted lines *NN*, *N'N'*, are the neutral lines. On such a motor, the coils would have to have one long lead and one short one, for the following reasons: Suppose the armature to have 99 coils, 99 slots, and 99 bars in the commutator; on all armatures of this kind, the coils are so made that they embrace as nearly as possible one-quarter of the total slots; also the two coil leads

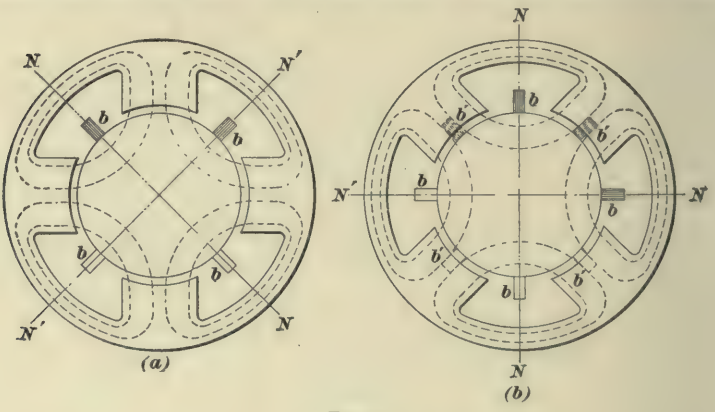



FIG. 5.

go into bars as nearly opposite as possible. On the armature in question (see Fig. 6), one side of the No. *1* coil would go into the No. *1* slot and the other side of the same coil would go into the No. *26* slot; i. e., to find in which slot the other side of the coil goes, begin at No. *1* and count off 26. The short-coil lead comes from the side of the coil that is in the No. *1* slot and connects to the No. *1* commutator bar directly opposite the No. *1* slot. The long coil lead coming out of the No. *26* slot goes around to the opposite side of the commutator and connects to bar No. *50*, as shown in Fig. 6 (*a*). The second coil drops into slots *2* and *27*, its short lead connecting to bar No. *2* and its long lead to bar No. *51*, and so on, until coil No. *25* is dropped into place, one side going

into slot No. *25* and the other side into slot No. *50*. When one-quarter of the coils have been put in place, one-half the slots have one side of a coil in them. As soon as slot No. *50* has one side of a coil in it, the winder starts at No. *50* again, and drops into it one side of another coil whose second side drops into slot No. *75* and whose long lead goes to bar No. *99*. Its short lead goes to bar No. *50*. If the No. *1* coil and the No. *26* coil only be put in place, we have the condition shown in Fig. 6 (*a*), where it can be seen that the four slots through which the current goes in its

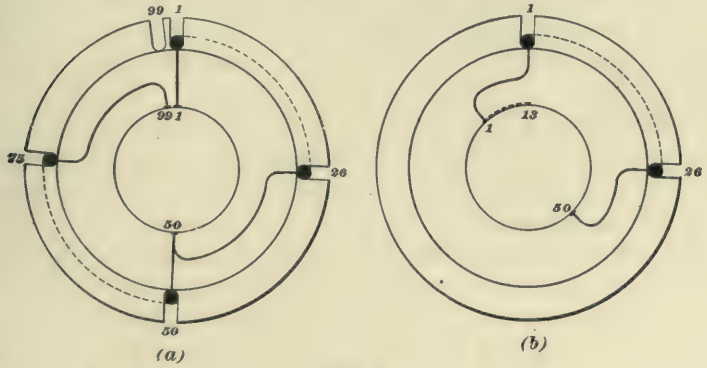



FIG. 6.

path from the No. *1* bar around the armature back to bar No. *99* are almost at right angles to each other, so that, since the four neutral points are also at right angles to each other when one wire is in the neutral field, all of those in series with it are in neutral fields also. In other words, when a brush touches any two bars at a time, all the coils in between those two bars are short-circuited at the same time, and they are in the same part, relatively, of the field. That is to say, if the No. *1* slot is just leaving the top pole piece, slots Nos. *26*, *50*, and *75* are just leaving the right, bottom, and left pole pieces, respectively.

In Fig. 5 four brushes are shown, but on account of the nature of the winding and connections on this type of armature, only two brushes are used—the two top brushes—and it can be readily appreciated that on a closed motor, a set of

bottom brushes would be a very bad feature to deal with, as a car would have to be run over a pit before its lower brushes could be properly renewed or inspected.

**7.** On motors such as the G. E. 800, the position of the neutral points, northeast and northwest, brings the brushes in the best possible place to be worked on; but on motors of the No. 3 type this is not so, and extra means must be taken to bring both brushes to the position of Fig. 5 (*a*). In Fig. 5 (*b*), the positions where the brushes would naturally fall on a motor of the No. 3 type is shown by the full-line blocks, and the positions where they are actually made to fall for convenience in inspection are shown by the dotted-line blocks.

Fig. 5 (*b*) is Fig. 5 (*a*) turned one-eighth of a circle to the right or to the left, thereby bringing one brush directly on top of the commutator and the other brush down on one side or the other, out of reach. To do away with this inconvenience, the coil leads on the No. 3 armature and on all armatures on motors of the same type are connected a little differently—they are given what is called a lead of one-eighth of a circle. This is shown in Fig. 6 (*b*), where the short lead in the coil going into the No. *1* slot, instead of connecting to the bar immediately opposite this slot, connects to a bar that is as many bars to the left as there are bars in one-eighth of the whole circle. The other coil lead goes to the bar as nearly opposite to this as possible. The rule for connecting up such an armature, then, is to count off 13 bars to the left of the No. *1* slot and put the coil lead from the No. *1* slot into this bar. To find out where the other lead goes, count off 50 as before, and put the lead into the No. *50* bar. The effect of giving the coil leads this advance of one-eighth of a circle is to make the short lead longer and the long lead shorter, with the net result that both leads become about the same length.

**8. Effect of Changing from Four Turns to Three Turns per Coil.**—The effect of replacing a four-turn coil by

one having three turns is to increase the speed, but decrease the starting power of the armature for a given current. It increases the speed, because there are not as many wires to cut the lines of force of the field, so that the counter E. M. F. being diminished, the armature takes more current, hence more power. The starting power is less, because the armature having less turns on it is not so strong a magnet and cannot, therefore, react on pole pieces with as much force as it did with four turns.

**9. Field Coil.**—The field coil on the No. 3 motor is of the same general shape as the field coil described in *Car Equipment*, Part 6, but its length is much greater in proportion to its width; its corners are rounded off to conform to the inside curve on the motor frame, so that when the field is drawn down to its place, no sharp edges are exposed to abrasion. When the field plate is put on it is a good idea to see that it is slightly bellied in the middle and in the opposite direction to that in which the bolts tend to bend it; for when the bolts are drawn down on the four corners, the shield tends to raise in the center so that all the bearing surface is on the ends, where it is most apt to give trouble; besides this, the central part of the shield is apt to raise above the horn of the pole piece and introduce some risk of rubbing the armature.

On No. 3 motors that have four-turn armatures, each field coil is wound with about 190 turns of No. 6 B. & S. gauge, double cotton-covered wire, making 760 turns of field wire per motor. Three-turn armatures are generally run with field coils wound with about 163 turns each of No. 5 B. & S. gauge, double cotton-covered wire, making 652 field turns per motor. All fields wound at the factory are made up of two parts, and these two parts are spliced together. The idea of this is to have both ends of the coil outside ends, and thereby do away with the bump caused by bringing the inside end to the surface. Of course, in winding any spool of more than one layer, there must be a bottom layer, and the inside end is the first turn of this layer. To

get the inside end to the surface, where it is connected to the lug, it must pass all the other layers and must be insulated from them; it is this insulation which causes the bump. On all old Westinghouse No. 3 fields, the ends of each coil wind-

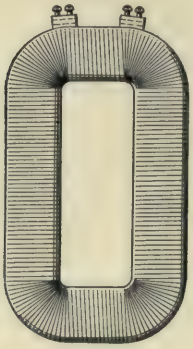


FIG. 7.

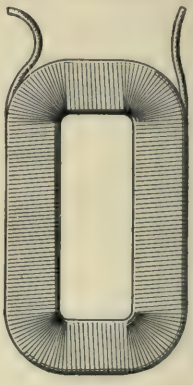


FIG. 8.

ing are connected to lugs on the ends of the coils, as indicated in Fig. 7, and the motor connecting wires also run into these lugs; but on many roads it is the custom to provide the coils with flexible leads as shown in Fig. 8.

**10.** Figs. 9 and 10 show two ways of connecting the coils and bringing out the car-wire leads. The dotted curved lines indicate the turns of wire in the field coil itself; the figures

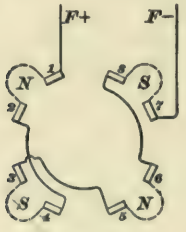



FIG. 9.

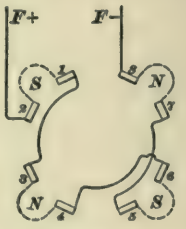



FIG. 10.

*1*, *2*, *3*, *4*, etc. indicate the metal lugs to which the two ends of the coil are connected; and the full lines, the pieces of insulated wire used to connect the several coils into one

continuous series. $F+$ and $F-$ are the leads, which are brought out to connect to the leads coming out of the car hose. It must be noticed that the only difference between the connections of Fig. 9 and those of Fig. 10 is that where a pole piece is a north pole in one case it becomes a south pole in the other, and vice versa. Assuming that the rest of the connections are right, the only thing to look out for is to see that the car leads come from the top lug on one top field coil and from the bottom lug on the other top coil.

**11. Wrong Field Connections.**—In Figs. 11, 12, 13, and 14 are shown several wrong connections that can be, and often are, made in replacing one, two, or more field coils.

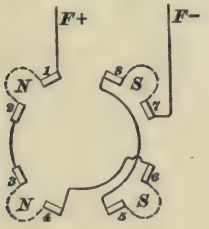



FIG. 11.

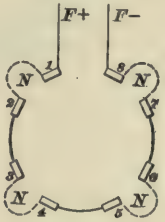



FIG. 12.

Let us assume Fig. 9 to be the standard connection that has been adopted on some particular road. In this view, beginning with the left-hand top lug, all the lugs are numbered in regular order from *1* to *8*, inclusive, in a direction contrary to that

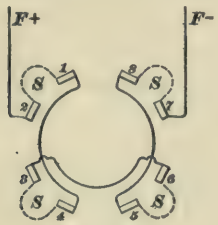



FIG. 13.

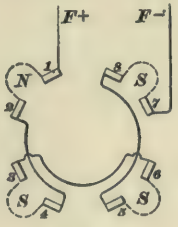



FIG. 14.

of the motion of the hands of a watch. Lug No. *2* is connected to lug No. *4*; No. *3* to No. *5*; No. *6* to No. *8*; Nos. *1* and *7* being reserved for the car-hose wires $F+$ and $F-$. In Fig. 11, the mistake has been made of connecting lug No. *2* to No. *3*,

instead of to No. *4*, with the result that the left-hand bottom coil is made a north pole, thereby bringing together two north poles on one side and two south poles on the other, making virtually of the motor a machine with two poles, consequently with the brushes in the wrong place. Under such a condition the car will start, but the faulty motor will spark while the two motors are in series, and will not only spark badly as soon as they are thrown to multiple, but is apt to flash over to the frame and ground a brush holder.

In Fig. 12, neighboring lugs have all been connected together; the current therefore passes through all the coils in a counter clockwise direction and makes all the poles north poles. A motor, so connected, would not start at all, alone; but as long as the two motors are in series, the car starts on the good motor, the current simply passing through the bad one as through any other part of the circuit. As soon as the motors go to multiple, there is a short-circuit and a fuse blows. Such a wrong connection as that shown in Fig. 12 should be evident from the fact that the two car leads $F+$ and $F-$ both come from top lugs—one should come from a bottom lug. In Fig. 13, the same mistake has been made, but in a little different way, with the result that all the poles are made south poles. This mistake should also be evident from the fact that the two car-hose leads both come from bottom lugs—one lead should always come from a top lug. In Fig. 14, lug *3* goes to *6* instead of to *5*. The result is three south poles and one north pole. The faulty motor sparks when in series with the good motor, but bucks as soon as the two motors are thrown over to multiple.

**12. The No. 3 Brush Holder.**—Fig. 15 is a rough sketch of the **No. 3 brush holder.** It is of the radial type, and has given such a long record of satisfaction that the Westinghouse Company have departed from it but very little in their design of brush holders for the more recent types of motors. It is as simple and at the same time as cheap as any such device can be made. In Fig. 15, *J* is the jaw or clamp that grips stick *N* made of wood and held by a yoke screwed to the

motor bearing, but not shown in the figure. *L* is the **shank** of the brush holder, and it might be called the critical part of the device, because in having new holders cast, it is very essential that the shank be of the right length. If it is too long, the brushes will be brought too close together on the commutator *C*, and if too short, they will set too far apart.

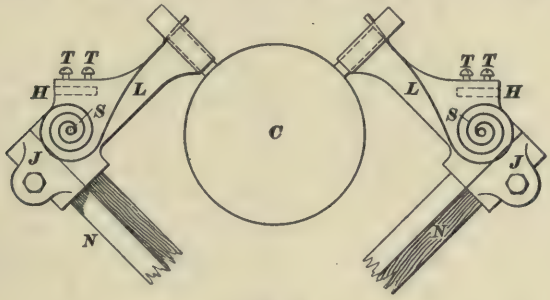



FIG. 15.

A fatal mistake can be made by confusing metal and wood patterns, as has been explained before. Also, an error can be introduced by selecting as a sample for the patternmaker, a brush holder that is itself a little off. *S* is the spring that holds the brush down on to the commutator. This spring is about the only thing that ever gets out of order if the motor is otherwise in good shape, but it is a very small job to renew it when occasion demands. *H* is a hole drilled in the holder to take the lead, and *T*, *T* are two screws to secure the lead firmly. Some barn men prefer to solder the lead in place, and it is not a bad idea. When it is desired to change brushes, the tension springs, of which there are two, one on each side of the shank *L*, are raised and rested on the side of the holder.

**13. Gearing.**—The gear most used for the No. 3 motor has 62 teeth in it, and the hub is of such thickness as will admit of boring to fit any axle up to $4\frac{1}{2}$ inches. The pinion is taper bored, and, when used with a 62-tooth gear, has 18 teeth in it, making a gear ratio of $\frac{62}{18} = 3.44$. Other ratios are $\frac{60}{20} = 3$, and $\frac{64}{16} = 4$. In every case, the sum of

the teeth in the gear and pinion is the same, or 80. It is, in nearly all cases, safe to increase the gear ratio on a motor, because the effect is to decrease the speed of the car, and hence the current that the motors will take; but it must be borne in mind that when the gear ratio is increased, the diameter of the gear is increased also, and the gear may be too large to go into the gear case adapted to the lower reduction. It is, however, not always a wise move to decrease the gear ratio on a motor in order to get a higher speed, because in so doing, the motor is called upon to take more current, and it may not be able to stand it. Unless one is an engineer and understands all these things himself, it is a wise plan, before putting into effect any contemplated change in gearing, to inform the makers of the motor of the proposed change, state the conditions under which the motors run, and ask for their advice.

The above remarks apply with equal force to all motors, but it has been thought well to introduce them here in order to call attention to them.

---

### WESTINGHOUSE 12A MOTOR.

**14. General Remarks.**—The Westinghouse No. 12 motor took the place of the Westinghouse No. 3 motor, and the No. 12 has in turn been superseded by the Westinghouse No. 12A, which differs from the No. 12 only in points of mechanical detail. In all the subsequent types of Westinghouse motors, the good points upon which the old No. 3 motor made its reputation have been adhered to and new features introduced. Among these strong points are the general shape of the No. 3, its convenience in shop work, the number of poles, character of insulation, simplicity, and quality of workmanship. On all types brought out since the No. 3 motor, the yoke or motor frame has been done away with and the armature hung from a projection on one of the motor shells in conjunction with a cap secured by bolts. Among the new features introduced are ventilation of armature, new method of grouping the coils, thereby doing away

with one-half the slots in the core, and the outboard design of armature bearings, whereby no grease can be thrown inside the motor shell. The clearance between the pole pieces and armature has been increased. This not only makes the armature less liable to get down on the pole pieces, but it makes the non-sparking range greater; i. e., the motor will stand more load with less sparking than it would were the clearance less. The No. 12A motor is made in two outputs, 25 horsepower and 30 horsepower. The 25-horsepower motor is adapted to conditions met with in ordinary street service. The 30-horsepower motors are wound for high speed and for low speed; the low-speed motors are used where there is not so much demand for speed as there is for hill-climbing ability; the low-speed 30-horsepower No. 12A motor has more pulling power than the high-speed motor. The 30-horsepower high-speed motor is adapted for use on roads where there are no grades, but where there is more of a demand for speed. The efficiency of the Westinghouse No. 12A motor is good, and the cost of maintenance low.

**15. Frame.**—The frame, comprising the shells, is of steel, and is, of course, in two parts, hinged together at *H*, *H*, *H*, *H*, in Fig. 16. Fig. 17 shows the motor swung open, in which position either of the lower field coils may be removed without disturbing any other part of the motor. When the motor is closed, Fig. 16, the two shells are held together by means of bolts passing through holes *b*, *b*, *b*, *b*. These bolts also serve as the bearing bolts for the armature. The pole pieces, of which there are four, are cast with the two shells. The top shell has a lid-covered opening to give access to the commutator and brushes for inspection; the lower shell has a hand hole for removing dirt, or wrenches, bolts, etc. that may have been dropped in from above.

**16.** Right here it will not be out of place to say that when a car with motors under it is shoved into a paint shop or carpenter shop to be worked on, the trap doors of the car and all motor lids and grease-cup covers should be in place, to avoid getting varnish on the commutators, wood splinters

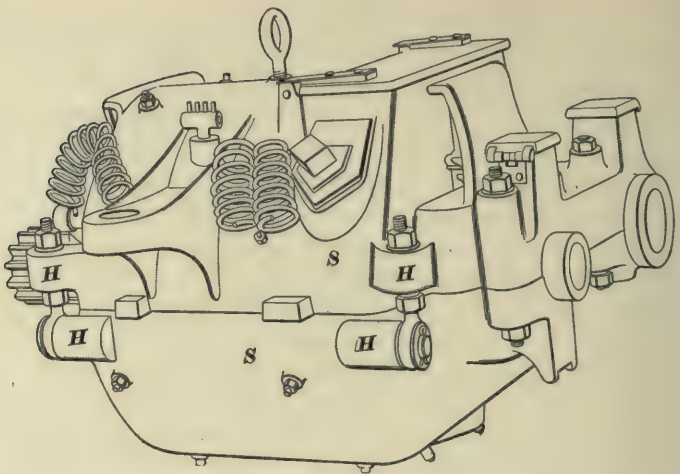



FIG. 16.

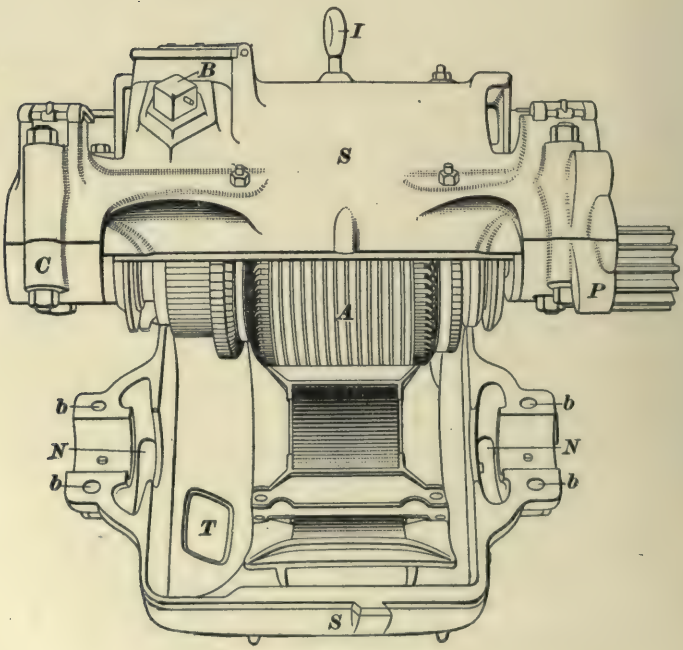



FIG. 17.

and paint brushes in the motors, bolts and small tools in the gear cases, and broken glass or other foreign matter in the grease cups. It is surprising what a collection of useful articles, varying in size from a cotter-pin to a step ladder, will find their way into a lot of motor shells in the course of a year, and the cause of a large percentage of the stripped armatures on any road can be traced to this source.

**17. The 12A Armature.**—The 12A armature, like all up-to-date armatures, is of the coil-wound ventilated type. This means that instead of winding the wire on to the core from a reel, as was done in early times, the coils are completed in themselves by being wound on a form, insulated, baked, and then placed in position by hand. This saves a great deal in the cost of the labor employed to wind an armature. To wind an armature by hand from the reel requires the services of a skilled armature winder; boys and even girls can get the coils ready for the core, and the same class of labor can put them in position. Until the 12A motor came out, it was the rule to have as many slots in the core as there were coils to be placed, or as there were bars in the commutator; but on the 12A armature, there are twice as many coils and twice as many bars as there are slots in the core. There are 93 bars and 93 active coils, but there are only 47 slots in the core. The way this is done is by grouping two coils together in one slot.

There are $46\frac{1}{2}$ active coils finished to complete the winding of a 12A armature, but each completed coil contains two coils in it. The two coils are in the same casing, but are insulated from each other, and each coil has two leads of its own. Since the commutator has 93 bars in it, and since each bar takes two leads, and also since there are 47 slots and each slot has four leads coming out of it, making 188 leads, it is easy to see that there are two leads more than there are places to put them. When the 47 coils are in place on the core, and the leads are connected down until the commutator is full, there are two leads left over, with no place to put them. These two leads are either cut off or are bent back

and insulated, so that the coil from which they come is a "dummy" coil or an idle coil in the armature, and this is why, as stated above, there are 47 completed coils needed to fill the core, but only 46½ of them are active. The armature is ventilated because the core has air passages in it, and from the nature of the coils on the ends there is a continuous path permitting a free circulation of air through the body of the core and up through the ends of the coils. The 12A armature is of relatively small diameter, so that when the power is shut off there is not much tendency for the armature to keep on turning on account of its inertia.

**18. Field.**—The field consists of 4 poles projecting radially inward from the shells already described. There are 4 field coils, one to each pole piece; the coils are wound on forms attached to a lathe; they are insulated with fuller board, mica, and tape, and are baked. One coil slips on over each pole piece and is held in place by brass plates that bolt to the frame. All field coils are wound alike and are wound with what is called a *No. 5 square wire*. This is about equivalent to a No. 4 B. & S. round.

**19. Brush Holder.**—The brush holder is practically the same as that on the No. 3 and needs no explanation.

**20. Replacing Parts.**—From the nature of its construction, the 12A motor admits of replacing a field or an armature without disturbing any other part. Iron hooks are provided on the ends to hold the armature up if it is desired to retain it in the upper shell when the motor case is opened.

## WESTINGHOUSE CONTROLLERS.

### WESTINGHOUSE 28A CONTROLLER.

**21.** Fig. 18 shows the Westinghouse No. 38 controller, which is practically the same as the 28A, the several parts of which, together with its car-wiring diagram, will now be taken up. The Westinghouse controllers differ very much

from those made by the General Electric Company, which were considered in *Car Equipment*, Part 7. . The different sections of the power drum are separated from each other by vulcabeston insulating rings *U*, *U*, *U*, etc., as shown in Fig. 18. The reverse device, shown at *D*, is of the disk

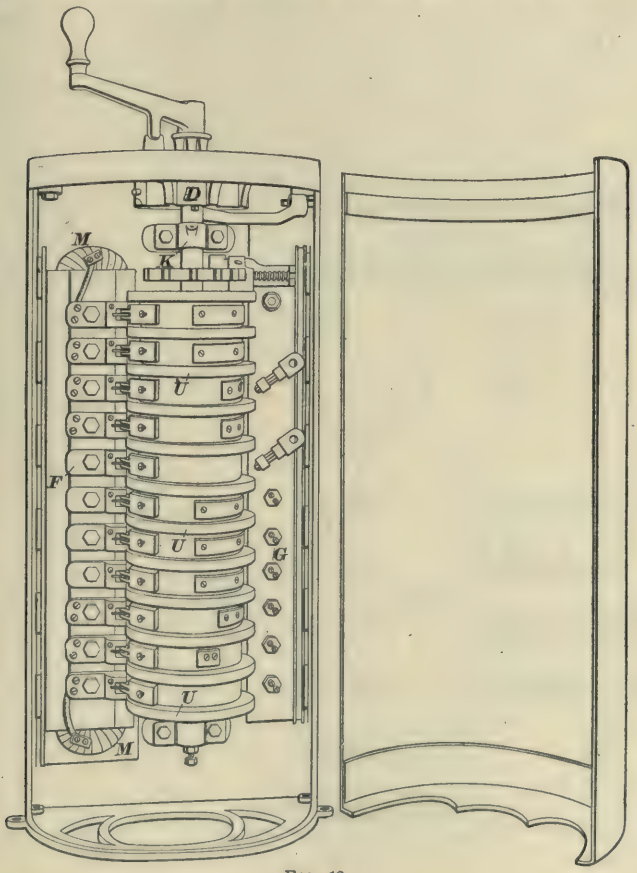



FIG. 18.

form instead of the drum type as in the General Electric Company's type K2. The power-drum finger board is on the left at *F*. Around the base of the finger board is wound a magnetic blow-out coil *M*, which by way of the fingers, which contain a great deal of iron, project lines of force

across the arc gaps and extinguish the arcs. The connecting board is in two sections; one section is at *G* in the right-hand part of the controller and the other is in the lower part, below the power drum. The 28A controller is a very good one, but is not in the same class with the K controllers of the General Electric Company, as is evidenced by the fact that the Westinghouse Company now ship K controllers with all their motors. As is the case with all up-to-date controllers, the 28A motor cut-outs are arranged so that when one motor is cut out, there is an interference with the power drum in such a way that it cannot be turned past the series notches. With one motor cut out, the 28A controller starts the car on the first notch, and gives the single motor full power on the fourth notch. The power and reverse handles interlock as on the type K2 and K11.

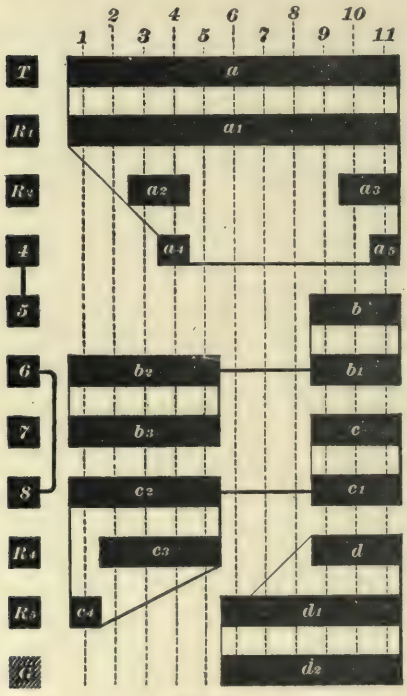



FIG. 19.

**22.** Fig. 19 shows the 28A power drum and the finger board on the left. This drum has four groups of rings; all rings marked *a* are connected together and should ring up together when tested with a magneto bell; the same is the case with the rings marked *b*, *c*, and *d*; but groups with different letters are insulated from each other. The vertical dotted lines show the several positions assumed by the drum in going from the first notch to the last one. Fingers *T*, $R_1$, $R_2$, $R_4$, $R_5$, and *G* are marked the same as they are on the actual controller. Fingers *4*, *5*, *6*, *7*, and *8* are not

marked at all on the actual controller, but are arbitrarily marked here for convenience in following the path of the current in succeeding diagrams. We will now take up the reverse-switch connections.

**23. The 28A Reverse Switch.**—On the 28A reverse switch, as on any other, the position of the reverse handle is supposed to indicate the direction in which the car will start as soon as the power drum is turned on. If the handle points ahead, the car should go ahead, and if it points back, the car should go back. Failure to have this condition observed is almost certain to result sooner or later in a loss of life or property.

Fig. 20 shows the connections of the 28A reverse switch. In this diagram, all the devices have been left out save the motors, resistances, and the reverse switch. All wires, instead of running to their respective controlling devices, are run direct to the reverse switch. Each device will thus be taken up alone and will then be brought into the car-wiring diagram one at a time, so that the function of each may be clearly seen. The wiring diagram as a whole will then be considered.

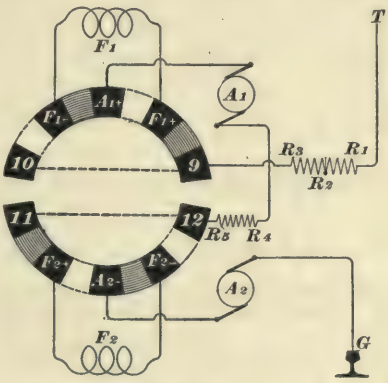


FIG. 20.

In Fig. 20, six points on the reverse switch are lettered the same as they are lettered on the actual reverse switch, but the four points *9*, *10*, *11*, *12* are here arbitrarily marked so that they can be intelligently referred to in tracing the path of the current through the switch and the devices attached to it. On the actual switch, these points are not named at all. The mechanical details of the moving parts of the switch are not shown in Fig. 20, but some light can be

thrown on these details by referring to Fig. 21, which shows the principle upon which the idea is carried out, but which is not an actual drawing of the device itself. *D D* is a vulcabeston, slate, or fiber flat disk upon the outside rim of which are screwed the brass tips *T*, *T*, *T*, *T*, which turn about center *O*. Handle *H* is pivoted at *O'* and can be moved ahead or back, but in the figure it is in the off-position, in which position it can be taken out. Posts $F_1-$, $A_1+$, $F_1+$, $F_2-$, $A_2-$, and $F_2+$, in Fig. 20, are stationary; besides having connecting posts to which wires can be run, they have switch blades against which brass tips *T*, *T*, *T*, *T* press when the handle *H*, and hence the lever *L*, is moved one way or the other. When the handle *H* is shoved ahead to the right, the connections are as shown by the shaded lines in Fig. 20, where $F_1+$ is connected to post No. *9*, $F_1-$ to $A_1+$, $F_2+$ to post No. *11*, and $F_2-$ to $A_2-$. In this position, the path of the current from the trolley *T* to the ground *G* is $T$–$R_1$–$R_2$–$R_3$–*9* across one of the drum tips to post $F_1+$, out through the No. 1 motor field, back to post $F_1-$, across another drum tip to post $A_1+$, out through the No. 1 motor armature and back through resistance coil $R_4$–$R_5$ to post *12*, thence across the dotted line (which indicates that posts *11* and *12* are permanently connected, as are posts *9* and *10*) to post *11*, through a third drum contact tip to post $F_2+$, from where it passes out through the No. 2 motor field, back to post $F_2-$, across the fourth and last drum contact tip to post $A_2-$, through the No. 2 motor armature to the ground at *G*. This ground is secured by grounding the negative brush lead of the No. 2 motor directly to the frame of the motor or to the ground wire. If the reverse handle *H* is thrown back, the drum contact tips take up the position shown by the double-dotted lines in Fig. 20, and the former connections are broken. Posts $F_1-$ and *10* are connected together, posts $F_1+$ and $A_1+$, $F_2-$ and *12*, $F_2+$ and $A_2-$, and the path of the current from

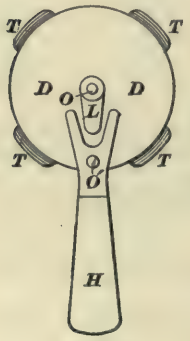


FIG. 21.

the trolley to the ground is $T$–$R_1$–$R_2$–$R_3$–*9*–*10*–$F_1$—, through the No. 1 motor field $F_1$+–$A_1$+, through the No. 1 motor armature $R_4$–$R_5$–*12*–$F_2$—, through the No. 2 motor field $F_2$+–$A_2$—, through the No. 2 armature to the ground at $G$, as before.

**24.** It must be noticed that when the reverse handle points ahead, the current enters the No. 1 motor field on the right-hand end and the No. 1 armature at the top brush holder; it goes into the No. 2 motor field at the left-hand end and into the No. 2 armature at the right-hand brush holder. When the reverse handle is thrown back, the current goes into the two armatures the same as it did before, but it goes into the No. 1 field at its left-hand end instead of the right, and into the No. 2 field at the right-hand end instead of the left, as it did when the reverse handle was set to send the car ahead. The fields, then, have been reversed instead of the armatures, as on the General Electric equipment.

**25. The 28A Cut-Out.**—The 28A cut-out consists of two sets of posts, four posts for each motor, with holes in them to take a plug, shaped to fit the holes. To operate the cut-out, the plug is taken by the handle, pulled out part of the way, and given a one-quarter turn; upon releasing the plug, a spring pulls it back home into its new position. The lower plug is for the No. 1 motor, the motor next to the trolley wire, and the upper plug is for the No. 2 motor, the motor next to the ground. In Fig. 22, all devices have been left out of the controller connections, except the cut-out device, to make the path of the current easier to follow. The cut-out posts have also been marked *13*, *14*, *15*, *16*, *17*, *18*, *19*, and *20* for the same reason. In the actual controller, these plugs are not marked at all.

In Fig. 22, both motors are shown cut in, in which position the plugs make contact between the posts that are up and down. As, for instance, the lower plug connects posts *15* and *16* on one side and posts *13* and *14* on the other, the

top plug connects posts *17* and *18* on one side and *19* and *20* on the other. Post *20* might just as well not be there, as far as being of any electrical use is concerned, because it is not connected to anything. It is put there not only to avoid having two sorts of cut-out devices in the controller, calling for two sorts of plugs, but it also serves as an additional mechanical support for the top plug, thereby making a good electrical contact more certain. In the position shown in Fig. 22, the path of the current is $T$–$R_1$–$R_2$–$R_3$–*13*–*14*–$F_1+$–$F_1-$–$A_1+$–$A_1-$–*15*–*16*–$R_4$–$R_5$–*17*–*18*–$F_2+$–$F_2-$–$A_2-$–$A_2+$ to the ground at $G$.

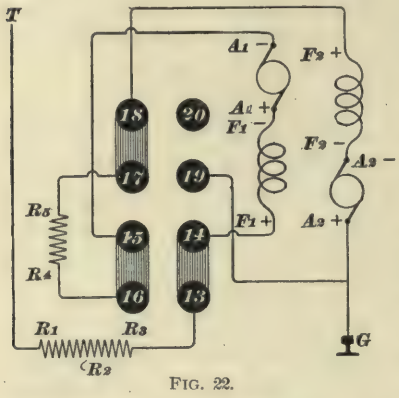


FIG. 22.

It will be noticed that the brush lead at which the current goes into the No. 2 armature is marked $A_2-$. Of course, the very fact that the current goes in at this brush holder makes it positive, but the lead is marked negative to indicate the fact already stated, that because the motors hang on the car truck back to back, their armatures must turn in opposite directions, in order to urge the car in the same direction, and if the current goes into both fields from the same end, it must enter the armatures at the front lead on one motor, and at the back lead on the other.

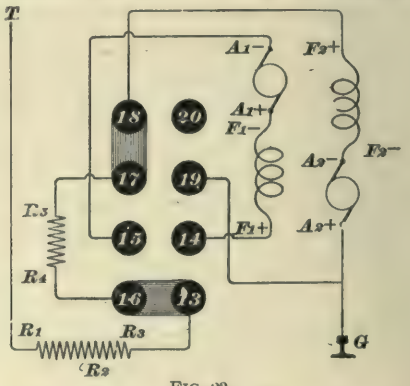


FIG. 23.

**26.** In Fig. 23, the No 1 motor is shown cut out; its plug has been given a one-quarter turn, breaking all connection between posts *13*

and *14*, and making a connection between lower posts *13* and *16*, thereby leaving the two ends of the No. 1 motor, connected to posts *14* and *15*, hanging in the air, as it were. The No. 1 motor is therefore cut out because it can get no current. The path of the current in this case is $T$–$R_1$–$R_2$ –$R_3$–*13*–*16*–$R_4$–$R_5$–*17*–*18*–$F_2+$ –$F_2-$ –$A_2-$ –$A_2+$ to the ground at $G$. The No. 1 motor is dead and out of action.

**27.** Fig. 24 shows the No. 1 motor cut in and the No. 2 motor cut out. In this case, a quarter-turn on plug No. 2 has broken the connection between posts *17* and *18* and made connection between posts *17* and *19* direct to the ground at $G$. One end of the No. 2 motor is left hanging in the air at post *18*, and the other end is grounded through its permanent ground connection. The motor is dead, and therefore cut out. The path of the current in this case is $T$–$R_1$–$R_2$–$R_3$ –*13*–*14*–$F_1+$ –$F_1-$ –$A_1+$ –$A_1-$ –*15*–*16*–$R_4$–$R_5$–*17*–*19* to earth at $G$.

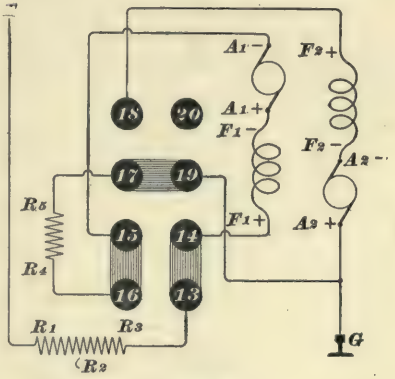


FIG. 24.

**28. Internal Connections of 28A Controller.** — Fig. 25 shows the internal connections of the 28A controller, which may be enumerated as follows: power-drum finger $T$ has no internal connection, but takes the car-trunk trolley wire direct; fingers $R_1$ and $R_2$ take the Nos. 1 and 2 car-resistance wires; *4* and *5* are joined together and to the wire which joins $X$ and *13*; *6* and *8* have no internal connection, but are joined together as shown; finger No. 7 is joined to cut-out post No. *17*; finger $R_4$ goes to connecting block $R_4$, thence to cut-out post No. *16*; finger $R_5$ has no internal connection, but takes the No. 5 car-resistance wire direct;

finger $G$ goes through block $G$ to cut-out post No. *19*; post $R_3$ takes the No. 3 resistance wire from the car hose on one

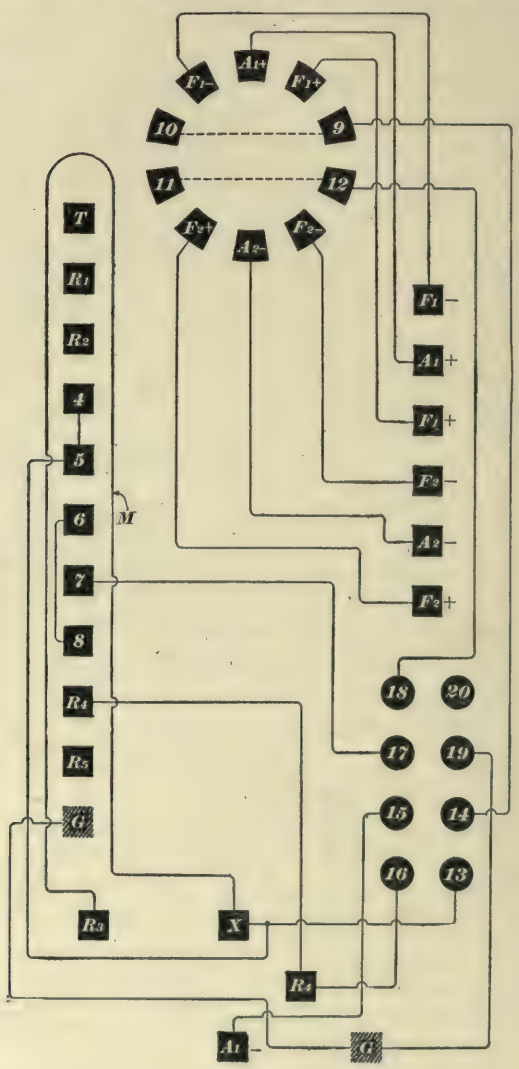



FIG. 25.

side, and on the other it takes the positive end of the blow coil $M$, which surrounds the finger board and whose other

end goes to block $X$. Connecting-board posts $F_1-$, $A_1+$, $F_1+$, $F_2-$, $A_2-$, $F_2+$ connect respectively to posts $F_1-$, $A_1+$, $F_1+$, $F_2-$, $A_2-$, $F_2+$ on the reverse switch. It will be noticed that the connecting board on the 28A controller is very much spread out over the controller back; part of it is on the power-drum finger board, the $T$, $R_1$, $R_2$, and $R_5$ fingers; part of it is in the lower part of the controller, the $R_3$, $R_4$, $A_1-$, and $G$ posts; and part of it is on the right-hand side of the controller, the $F_1-$, $A_1+$, $F_1+$, $F_2-$, $A_2-$, $F_2+$ posts.

**29. General Plan of Controller Connections.**—Fig. 26 shows the 28A controller-wiring diagram. It is not what is called a *car-wiring diagram* (although it can be used as such by a man who knows his business), because it fails to show the hose wires plainly, omits some of the safety devices, and does not show the other devices in their proper relative positions. Such a diagram, however, serves well to show the path of the current in the several combinations made by shoving the power drum step by step from the first notch series to the last notch multiple. As in the case of the General Electric Company's K2 controller, there are more positions than notches, and all the notches are not running notches. The vertical dotted lines in Fig. 26 indicate the eleven positions on the 28A controller. In this figure, both motors are cut in, as indicated by both plug connections being vertical. The reverse switch is supposed to be at "go-ahead."

**30.** On the *first position*, the path of the current is $T$–$a$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$R_3$–$M$–$X$–13–14–9–$F_1+$–$F_1+$, through No. 1 motor field, $F_1-$–$F_1-$–$A_1+$–$A_1+$–$A_1+$, through the No. 1 armature, $A_1-$–15–16–$r_4$–$r_5$–$R_5$–$c_4$–$c_2$–8–6–$b_2$–$b_3$–7–17–18–12–11–$F_2+$–$F_2+$, through the No. 2 motor field, $F_2-$–$F_2-$–$A_2-$–$A_2-$, through the No. 2 motor armature to the ground at $G$. The combination on the first notch, then, is two motors in series, with all the resistance in both rheostats. The first position is the first notch, but it is not a running notch, and it should not be used except in starting and in reversing the car in time of trouble.

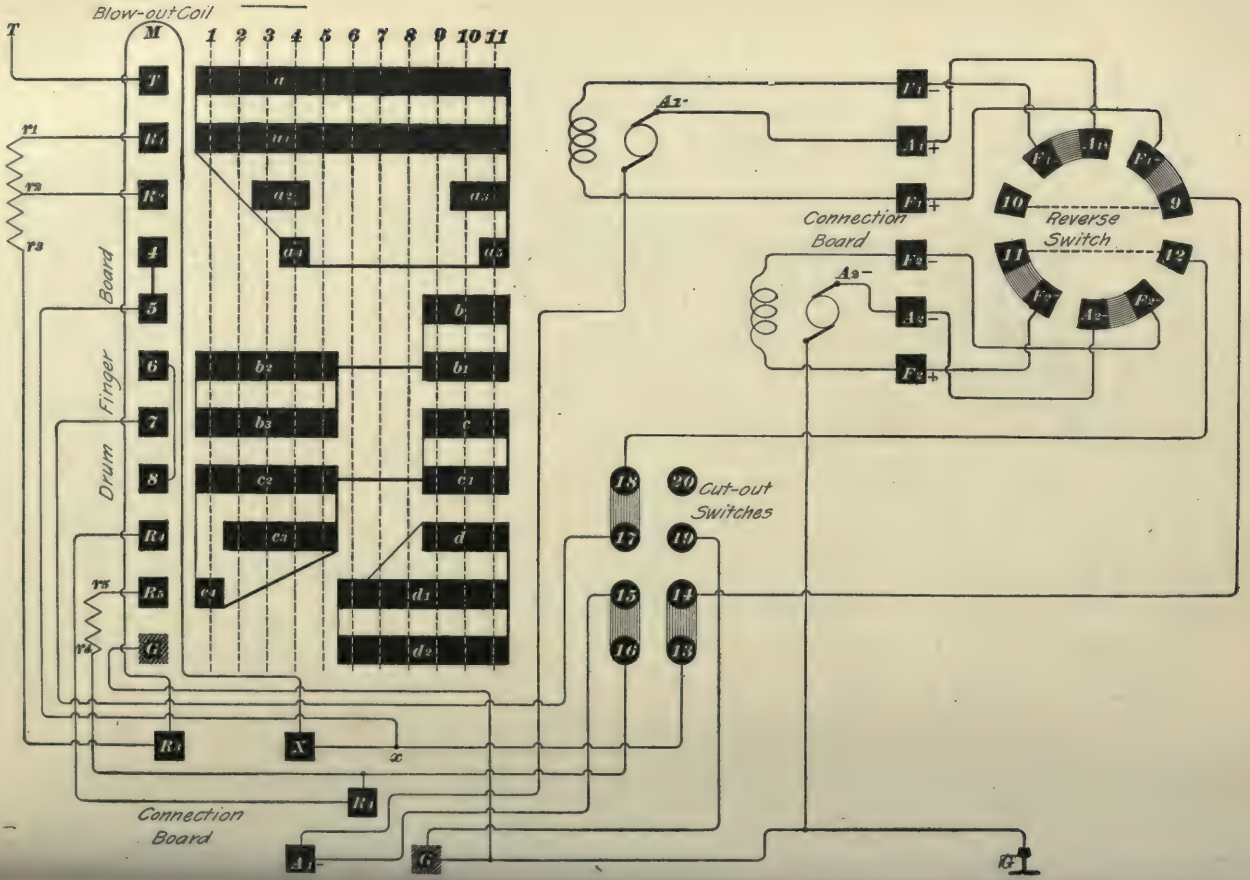

Blow-out Coil
T
M
1 2 3 4 5 6 7 8 9 10 11
Finger Board
Drum
Connection Board
Connection Board
Reverse Switch
Cut-out Switches
18
20
17
19
15
14
16
13
10
9
11
12
x

FIG. 96

**31.** On the *second position*, the $R_4$ finger makes contact with the $c_3$ drum tip and cuts out the resistance included between $r_4$ and $r_5$, that is, the entire resistance of the small rheostat. The current, instead of going through the small rheostat, goes up to post $R_4$, and thence through wire $R_4$, $R_4$, to finger $R_4$, to drum tip $c_3$ to $c_2$–8–6–$b_2$–$b_3$–7, and so on. The path of the current on the second position is $T$–$T$–$a$–$a_1$ –$R_1$–$r_1$–$r_3$–$R_3$–$M$–$X$–13–14–9–$F_1$+–$F_1$+, through the No. 1 motor field, $F_1$—–$F_1$—–$A_1$+–$A_1$+, through the No. 1 motor armature, $A_1$—–15–16–$R_4$–$R_4$–$c_3$–$c_2$–8–6–$b_2$–$b_3$–7–17–18–12–11 –$F_2$+–$F_2$+, through the No. 2 motor field, $F_2$—–$F_2$—–$A_2$— –$A_2$—, through the No. 2 motor armature to the ground at $G$. The net result of passing to the second position, then, is to cut out a part of the starting coil, leaving the two motors in series with less resistance than was in on the first notch. The second position is a marked notch, but not a running notch.

**32.** On the *third position*, finger $R_2$ makes contact with drum tip $a_2$ and cuts out that part of the resistance that is included between $r_1$ and $r_2$. The path of the current then becomes $T$–$T$–$a$–$a_1$–$a_2$–$R_2$–$r_2$–$r_3$–$R_3$–$M$–$X$–13–14–9–$F_1$+–$F_1$+, through the No. 1 motor field, $F_1$—–$F_1$—–$A_1$+–$A_1$+, through the No. 1 motor armature, $A_1$—–15–16–$R_4$–$R_4$–$c_3$ –$c_2$–8–6–$b_2$–$b_3$–7–17–18–12–11–$F_2$+–$F_2$+, through the No. 2 motor field, $F_2$—–$F_2$—–$A_2$—–$A_2$—, through the No. 2 motor armature to the ground at $G$. All of the small starting coil is still cut out, and part of the big one, so that on the third position, the two motors are still in series, but have less resistance in series with them than they had on the second notch. The third position is a marked notch, but is not a running notch.

**33.** On the *fourth position*, the No. 4 finger makes contact with the $a_4$ drum tip and cuts out that part of the resistance coil that lies between $r_2$ and $r_3$; the $R_5$ finger still making no contact with any drum tip, the small starting coil is still cut out, so that on the fourth position the motors

are in series, but have no resistance in ahead of them. The fourth position is marked as the fourth notch, but it is also a running notch. On the 28A controller, then, the fourth notch is the series running notch, and is the only series notch that can be so used. The path of the current on the fourth notch is *T–T–a–$a_1$–$a_2$–$a_4$–4–5–x–13*, etc., and so on as on the third notch.

**34.** On the *fifth position*, the $R_2$ finger leaves the $a_2$ drum tip and the No. 4 finger leaves the $a_4$ drum tip, so that the two parts of the large starting coil are once more let into the circuit; but as the $R_5$ finger still hangs in the air, the small rheostat ($r_4$, $r_5$) remains cut out, and the path of the current becomes *T–T–a–$a_1$–$R_1$–$r_1$–$r_3$–$R_3$–M–X–13–14–9–$F_1$+–$F_1$+–$F_1$––$F_1$––$A_1$+–$A_1$+–$A_1$––$A_1$––15–16–$R_4$–$R_4$–$c_3$–$c_2$–8–6–$b_2$–$b_3$–7–17–18–12–11–$F_2$+–$F_2$+–$F_2$––$F_2$––$A_2$––$A_2$––$A_2$––G*, which path is the same as it was on the second notch—the two motors in series and the large starting coil in series with them. The fifth position is not a notch, but is called a *change* position or position of *transition*, because it is used in changing the motors from series to multiple. The resistance coil is cut in again, to lessen the shock in passing from series to multiple, as, when this change is made, one motor is dropped out and is picked up again. If there were no coil in ahead of it, the motor would be placed right across the line, which would be a very bad thing for both the motor and the passengers, and especially so if the car happened to be ascending a steep grade with a heavy load, for, under this condition, the car has a tendency to halt when one motor is dropped, thereby depriving the car of that motor's share of the pulling power, and the dropped motor is picked up when the speed is so low that it has no chance to pick up its counter E. M. F. The flow of current through it under this condition is, of course, large.

**35.** On the *sixth position*, fingers 6, 7, 8, and $R_4$ pass off their drum tips, and fingers $R_5$ and $G$ make contact for the first time with the drum on tips $d_1$ and $d_2$. The path of the

current up to the splice just above block $R_4$, is $T$–$T$–$a$–$a_1$–$R_1$ –$r_1$–$r_2$–$r_3$–$R_3$–$M$–$X$–*13*–*14*–*9*–$F_1+$–$F_1+$–$F_1-$–$F_1-$–$A_1+$–$A_1+$ –$A_1-$–$A_1-$–*15*–*16* to splice just above post $R_4$. At the splice, the circuit splits into two paths; one path is $r_4$–$r_5$–$R_5$ –$d_1$–$d_2$–$G$ to the ground; the other path is post $R_4$ to finger $R_3$ and ends there, because finger $R_4$ does not touch a drum tip, but hangs in the air. The true path of the current, then, is $T$–$T$–$a$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$R_3$–$M$–$X$–*13*–*14*–*9*–$F_1+$–$F_1+$–$F_1-$ –$F_1-$–$A_1+$–$A_1+$–$A_1-$–$A_1-$–*15*–*16*–$r_4$–$r_5$–$R_5$–$d_1$–$d_2$–$G$. It can be seen that on the sixth position only the No. 1 motor is in circuit, and the car, therefore, runs on a single motor, but this is for a very short time, and all the resistance in both of the starting coils is in series with the single motor.

**36.** The *seventh* and *eighth positions* are the same as the sixth position, and none of them are notches; they are change positions, and are put there for two reasons: One of them is to increase the air gap between the series and multiple sides of the drum, and thereby help to put out the arc that tends to form there. The other object in making three positions instead of one is to increase the length of this gap and give more time to put out the arc.

**37.** On the *ninth position*, fingers *5*, *6*, *7*, *8*, and $R_4$ make contact with drum tips $b$, $b_1$, $c$, $c_1$, $d$, and the path of the current becomes $T$–$T$–$a$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$R_3$–$M$ up to point $X$; at the splice between $X$ and *13*, the current splits; part of it takes the path $X$–*5*–$b$–$b_1$–*6*–*8*–$c_1$–$c$–*7*–*17*–*18*–*12*–*11*–$F_2+$–$F_2+$ –$F_2-$–$F_2-$–$A_2-$–$A_2-$–$A_2-$ to the ground at $G$; and part of it takes the path *13*–*14*–*9*–$F_1+$–$F_1+$–$F_1-$–$F_1-$–$A_1+$–$A_1+$ –$A_1-$–$A_1-$–*15*–*16*–$R_4$–$R_4$–$d$–$d_1$–$d_2$–$G$. The first path is through the No. 2 motor; the second path is through the No. 1 motor; the two motors are in multiple, and the whole of the large rheostat is in series with both. The ninth position is a notch, but is not a running notch, and should not be rested on.

**38.** The *tenth position* is the same as the ninth, except that finger $R_2$ now touches drum tip $a_3$ and cuts out that part

of the resistance that lies in between $r_1$ and $r_2$; the path of the current to $M$ is $T$–$T$–$a$–$a_1$–$a_3$–$R_2$–$r_2$–$r_3$–$R_3$–$M$, beyond which it is the same as in the last position. The tenth position is a marked notch, but not a running notch; in it the two motors are in multiple, and the two in multiple are in series with that part of the large coil that lies between $r_2$ and $r_3$.

**39.** In the *eleventh* and last position, finger *4* makes contact with drum tip $a_5$ and cuts out section $r_2$ and $r_3$ of the starting coil; this leaves none of the starting coil in circuit at all, so that on this position, the two motors are in full multiple across the line. The eleventh position is therefore a running position, and should be run on as much as possible, in preference to the two positions just before it. The path of the current up to *5*, is $T$–$T$–$a$–$a_1$–$a_3$–$a_5$–*4*–*5*; here the current splits; part of it takes the path *5*–$x$–*13*–*14*–*9*–$F_1+$ –$F_1+$ –$F_1-$ –$F_1-$ –$A_1+$ –$A_1+$ –$A_1-$ –$A_1-$ –*15*–*16*–$R_4$–$R_5$–$d$–$d_1$–$d_2$–$G$, through the No. 1 motor, and part of it takes the path *5*–$b$–$b_1$ –*6*–*8*–$c_1$–$c$–*7*–*17*–*18*–*12*–*11*–$F_2+$ –$F_2+$ –$F_2-$ –$F_2-$ –$A_2-$ –$A_2-$ –$A_2-$ –$G$, through the No. 2 motor.

**40. General Remarks.**—The 28A controller has four notches in series and three in multiple. It has one running notch in series and one in multiple. The first position is the first notch; the second position is the second notch; the third position, the third notch; the fourth position, the fourth notch, which is the series-running notch; the ninth position is the fifth notch; the tenth position, the sixth notch; the eleventh position, the seventh notch, which is the last notch, and is the multiple-running notch.

There is one position, known as the *intermediate position*, about which nothing has been said so far; this position lies in between the fifth and sixth positions, and in it the $R_5$ and $G$ fingers make contact with the $d_1$ and $d_2$ drum tips, before the No. *6*, No. *7*, No. *8*, and $R_4$ fingers cease to make contact with the $b_2$, $b_3$, $c_2$, and $c_3$ drum tips; there is a brief interval of time when all six of these fingers touch the drum at once. During this brief interval, the path of the current is $T$–$T$–$a$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$R_3$–$M$–$X$–*13*–*14*–*9*–$F_1+$ –$F_1+$ –$F_1-$

$-F_1--A_1+-A_1+-A_1--A_1--15-16$ to the splice just above post $R_4$, where the current splits, part of it taking the path $R_4-R_4-c_3-c_2-8-6-b_2-b_3-7-17-18-12-11-F_2+-F_2+-F_2--F_2--A_2--A_2--A_2--G$ through the No. 2 motor, and part of it taking the path $r_4-r_5-R_5-d_1-d_2-G$ through the small starting coil. The small starting coil is, then, in multiple with the No. 2 motor, and the two in multiple are in series with the No. 1 motor. This disposition of the small starting coil makes the arcing less on the No. 2 motor drum tips and fingers when the No. 2 motor is dropped out of the circuit, but it is easy to see that to rest on this intermediate position for any length of time, would be a bad thing for the small starting coil, because it would then carry all the current alone. It is, however, in series with the large coil and the No. 1 motor.

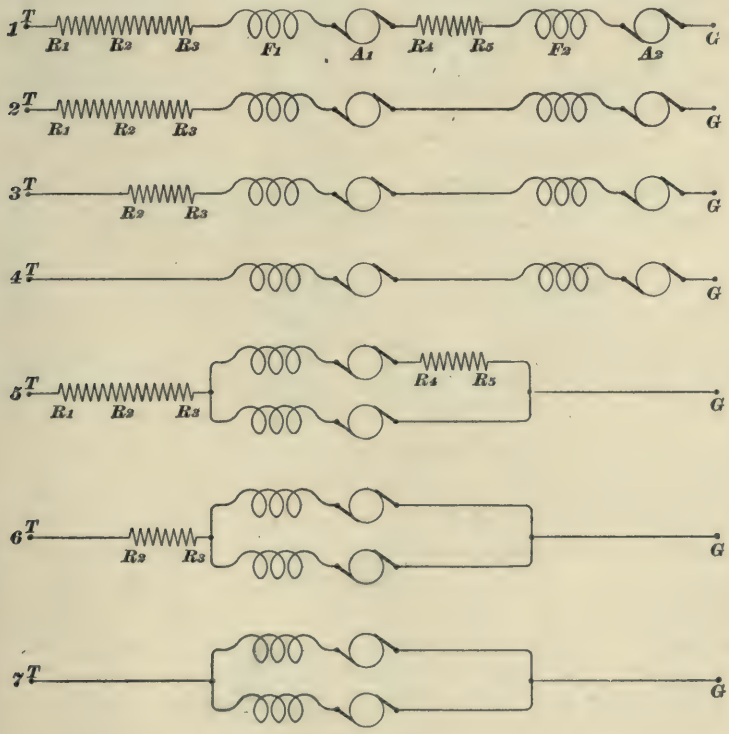



FIG. 27.

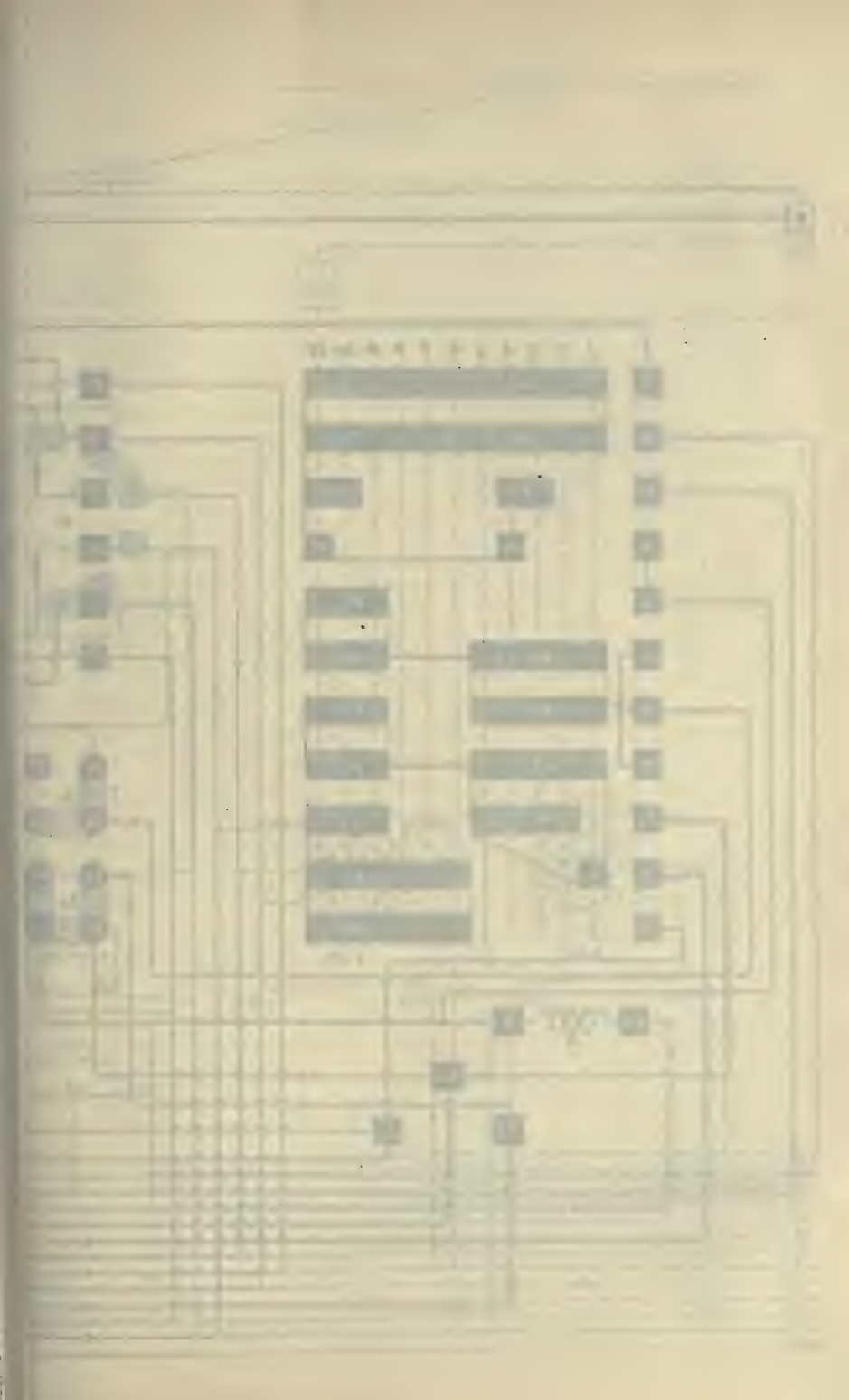
**41.** Fig. 27 is a sketch of the connections made by the 28A drum in going from No. *1* notch to No. *7*.

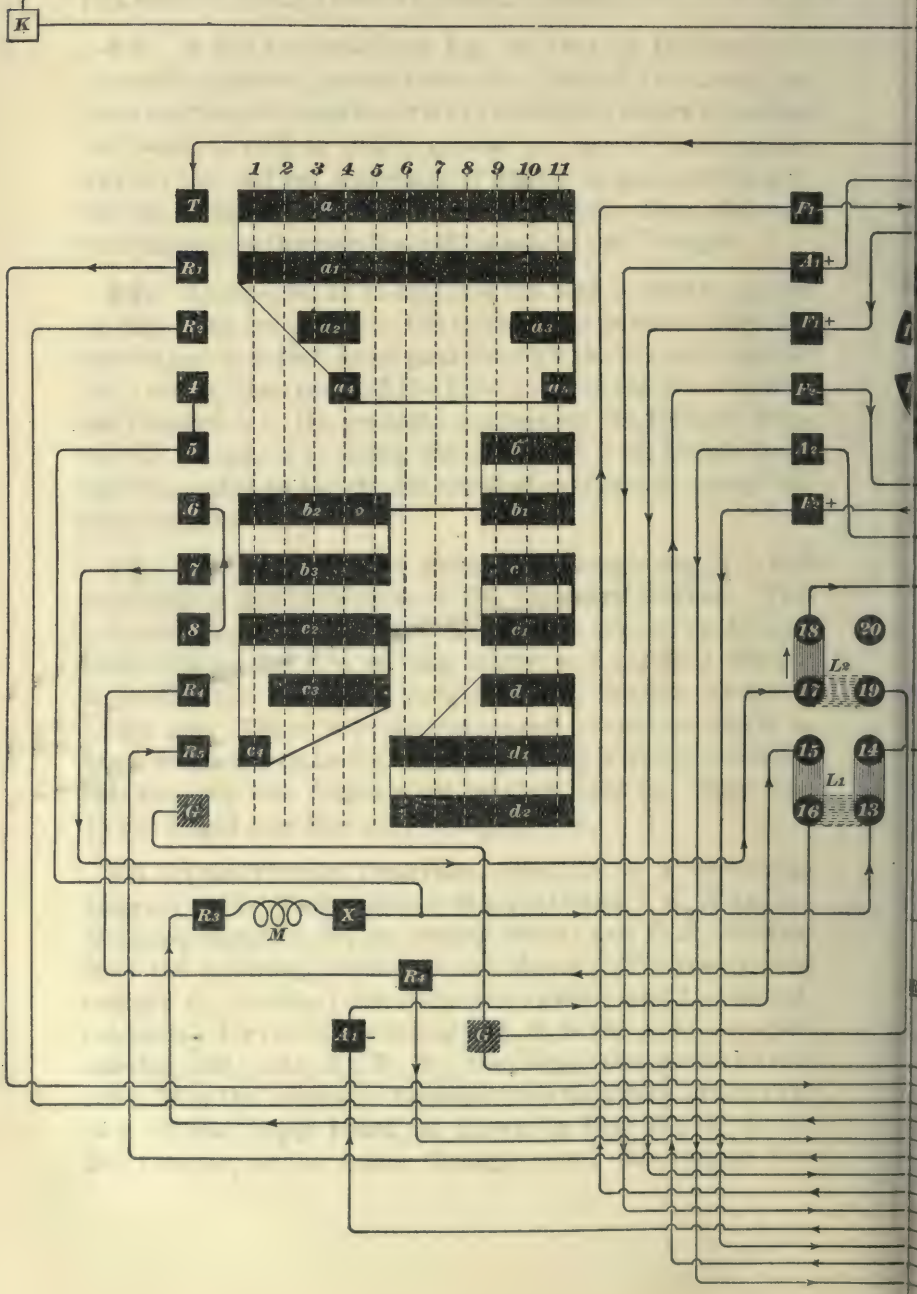
**42.** It will be seen from Fig. 26, that on the 28A controller the current passes through a part of the drum, the large starting coil, and several of the fingers, before it reaches the blow-out coil, so that a ground on any of these points will cut the coil out and make it unable to put out the arc. On the General Electric Company's K controllers, the current must pass through the coil to get to the *T* finger.

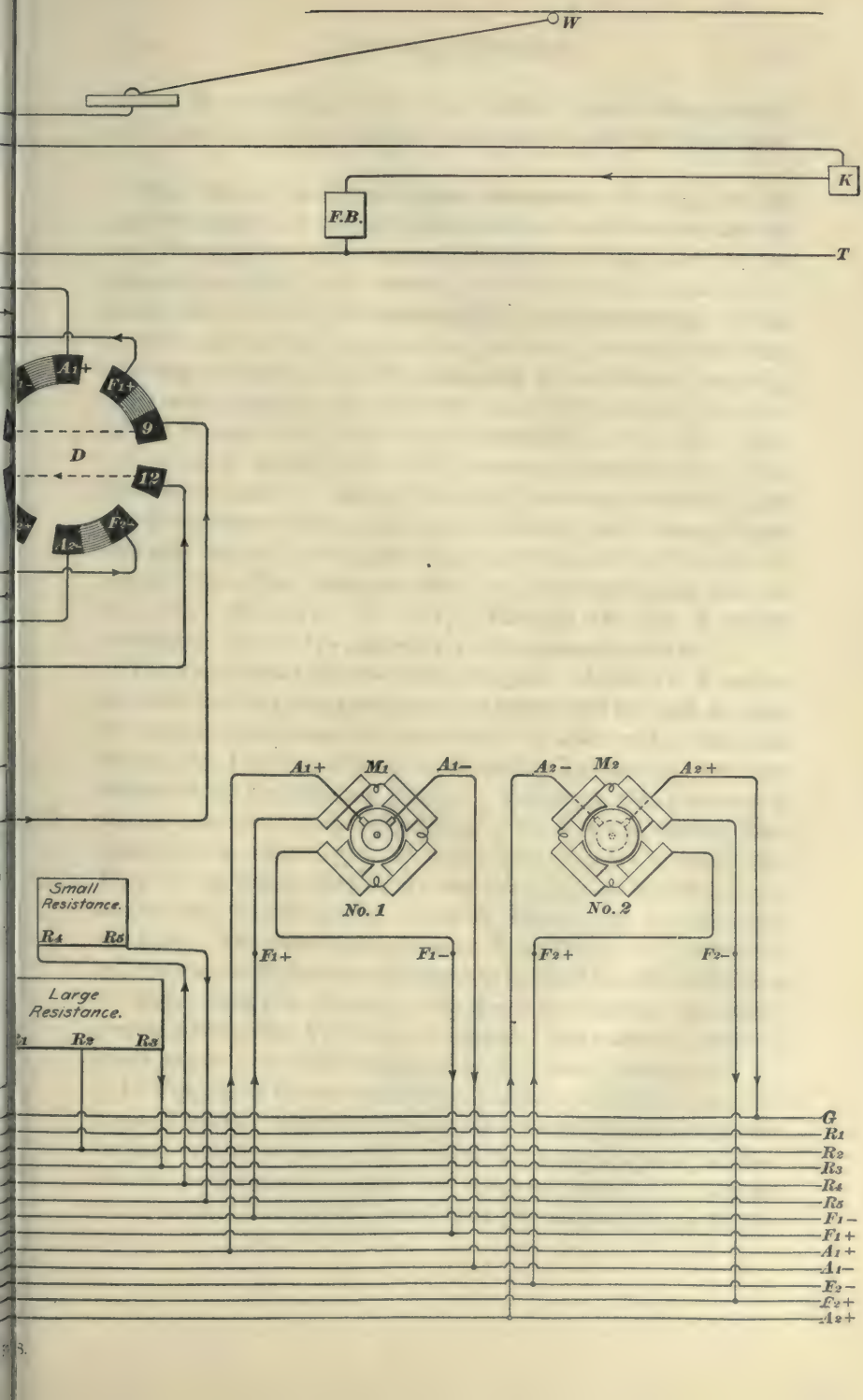
**43.** Another point to notice is the way in which the two starting coils are placed in the circuit; the current, when the motors are in series, must pass through the big coil into the No. 1 motor, then through the little coil into the No. 2 motor, and through it to the ground; whereas, on the General Electric K, K2, and K11 types, the resistance is all in one starting box, and is in the circuit ahead of everything, except the blow magnet.

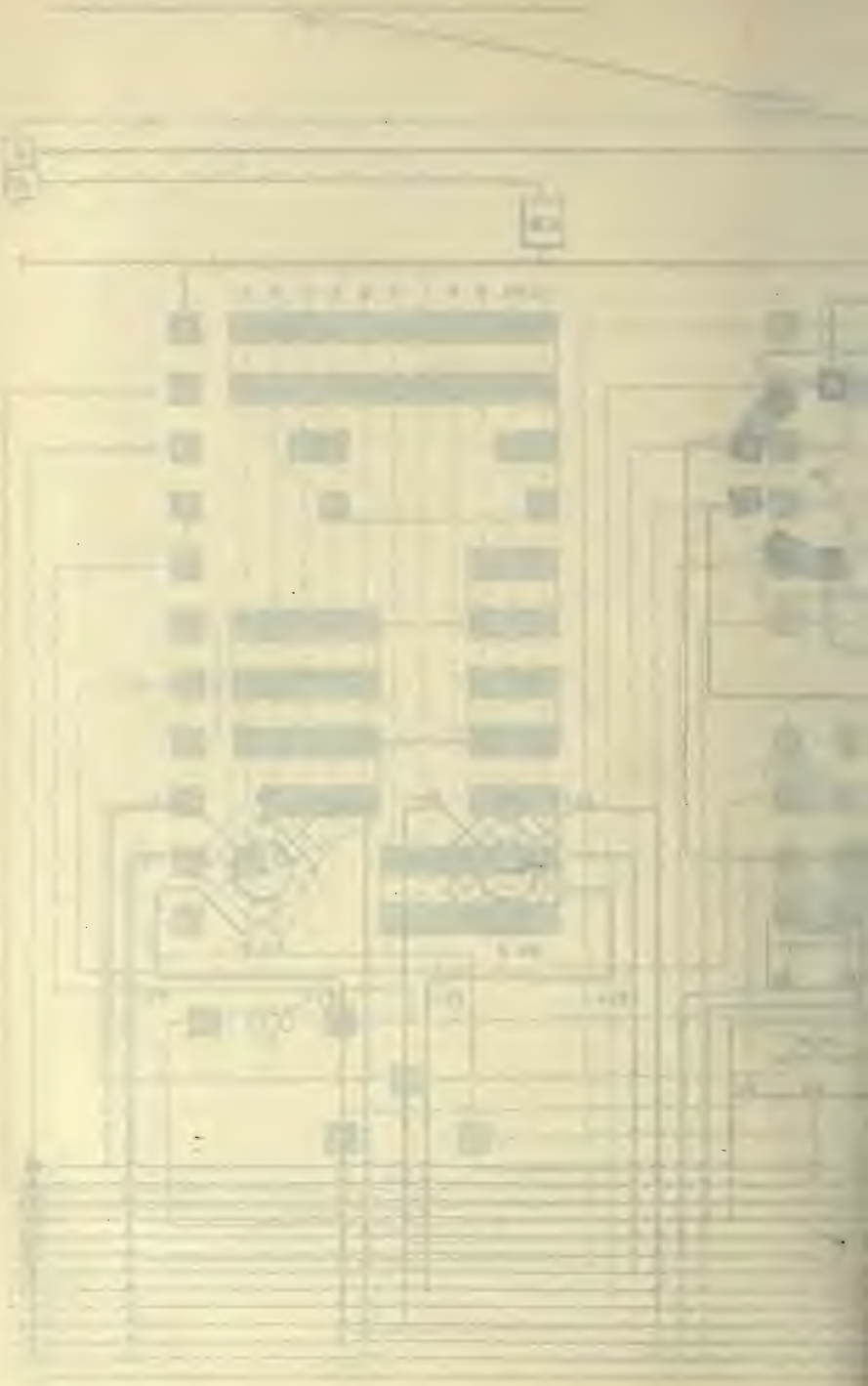
**44.** The weakest part about a Westinghouse No. 28A controller is the insulation of the blow-out magnet. This coil seems to have a strong inclination to ground to the controller frame, but it is an easy matter to fix it so it will not do so; a little skill, good judgment, and flexible mica will do the job. There is a case on record where two 28A's, so fixed, remained out on the road so long without attention that the shop men forgot what car they were on. Shop men do not forget cars that give much trouble.

**45. Car-Wiring Diagram.**—Fig. 28 is a car-wiring diagram of the Westinghouse 28A controller. *K*, *K* are the two hood switches; *W*, the trolley wheel; and *F. B.*, the fuse box; the lightning arrester is not shown; *D* is the reverse switch; $L_1$, the No. 1 motor cut-out switch; and $L_2$, the cut-out switch for the No. 2 motor; $R_4, R_5$ is the small one-part starting coil; and $R_1$, $R_2$, $R_3$, the large two-part starting coil; *M* is the magnetic blow-out coil that goes around the base of the finger board, as shown in Fig. 26; $M_1$ is the No. 1 motor, or the motor through which the current first




K
1 2 3 4 5 6 7 8 9 10 11
T
R1
R2
4
5
6
7
8
R4
R3
G
a
a1
a2
a3
a4
a5
b
b1
b2
b3
c
c1
c2
c3
c4
d
d1
d2
F1
A1+
F2+
F2
A2
A3+
18
20
L2
17
19
15
14
L1
16
13
R3
M
X
R4
A1
G


W
K
F.B.
T
A1+
F1+
9
D
12
A2−
F2−
A1+
M1
A1−
No. 1
A2−
M2
A2+
No. 2
Small Resistance.
R4
R5
Large Resistance.
R2
R3
F1+
F1−
F2+
F2−
G
R1
R2
R3
R4
R5
F1−
F1+
A1+
A1−
E2−
E2+
A2+



passes in its passage from the trolley wire to the ground; $M_2$ is the No. 2 motor, or the motor next to the rail or ground.

**46. Notes on Car-Wiring Diagram.**—In Fig. 28, the cut-out plugs are shown turned so that both motors are cut in. The path of the current from the trolley wire to the ground on the first notch is *W–K–K–F.B.–T–a–*$a_1$*–*$R_1$, along the car wire, as indicated by the arrowhead, to the positive end of the large starting coil at $R_1$, through the large starting coil and out at $R_3$, along the $R_3$ car wire to post $R_3$, into and through the blow-out coil *M–13–14–9–*$F_1$+ –$F_1$+ –$F_1$+, through the No. 1 motor field $F_1$– –$F_1$– –$F_1$– –$A_1$+ –$A_1$+ –$A_1$+, through the No. 1 motor armature $A_1$– –$A_1$– –*15–16*, to post $R_4$; thence on the $R_4$ car wire to the $R_4$ post on the positive end of the small starting coil, through this coil and out at $R_5$ to finger $R_5$–$c_4$–$c_2$–*8–6–*$b_2$–$b_3$–*7–17–18–12–11* –$F_2$+ –$F_2$+ –$F_2$+, through the No. 2 motor field, out at $F_2$– –$F_2$– –$F_2$– –$A_2$– –$A_2$– –$A_2$–, through the No. 2 motor armature, out at $A_2$+, directly to the ground wire at *G*.

The two dotted circles in the diagram of the No. 2 motor indicate the fact that the motor is turned end for end, so that its commutator cannot be seen from the same end as can that of the No. 1 motor, whose commutator outline is therefore indicated by the full-line circles. Although this point may not be brought up in connection with each car-wiring diagram to be taken up, it is nevertheless true of them all. Post $R_4$ has three wires in it; one wire goes to the No. 1 cut-out switch, block *16*, one to the $R_4$ finger, and one into the car hose. The wire between post $R_4$ and finger $R_4$ can carry no current until the second position is reached, for until then $R_4$ finger hangs in the air. For the same reason, the splice running from the *X–13* wire to finger *5* can carry no current until finger *4*, to which finger *5* is connected, touches $a_4$.

In Fig. 28, only one controller is shown connected up. To connect up the other one, it is only necessary to connect the broken-ended wires in the lower right-hand corner of the sketch, to the posts marked the same as these wires are on their ends. It must be noted that the wires that go to the

No. 2 controller are marked to allow for the fact, already alluded to, that since the two controllers are on opposite ends of the car, and therefore stand face to face, either both field or both armature terminals must be reversed in order to have the position of the reverse handle indicate the direction in which the car will start. In Fig. 28, the reverse switch is so placed that the car will move in the direction indicated by the slant of the trolley pole.

**47. Cut-Out Switches.**—In Fig. 28, both motors are cut in. In order to cut out the No. 1 motor, the lower plug must be pulled part of the way out and given a one-quarter turn; this breaks the connection between blocks *13* and *14* and blocks *15* and *16* and makes a connection between blocks *13* and *16*, as indicated by the dotted lines between these blocks. The turning of the plug acts upon an interference so that the drum cannot be turned past the fourth position or notch. The path of the current on the first notch is, then, *W*–*K*–*K*–*F. B.*–*T*–*a*–$a_1$–$R_1$–$R_1$–$R_2$–$R_3$–$R_3$–*M*–*X*–*13*–*16*–$R_4$–$R_4$–$R_5$–$R_5$–$c_4$–$c_2$–*8*–*6*–$b_2$–$b_3$–*7*–*17*–*18*–*12*–*11*–$F_2+$–$F_2+$–$F_2+$–$F_2-$–$F_2-$–$F_2-$–$A_2-$–$A_2-$–$A_2-$–$A_2+$ to the ground wire at *G*. One end of the No. 1 motor goes to cut-out block *14*, and the other end to cut-out block *15*, so that when the cut-out plug is given a quarter-turn, leaving blocks *14* and *15* hanging in the air, it leaves the No. 1 motor also hanging in the air, so that no current can get to it. When the current gets to block *13*, instead of taking the path *14*–*9*–$F_1+$–$F_1+$–$F_1+$–$F_1-$–$F_1-$–$F_1-$–$A_1+$–$A_1+$–$A_1+$–$A_1-$–$A_1-$–*15*, and through the No. 1 motor to block *16*, it passes directly across the plug to block *16*, thence on to the No. 2 motor. The No. 1 motor has been left out of the circuit, and its place taken by a strip of metal.

To cut out the No. 2 motor plug, $L_2$ is given a quarter-turn; this breaks the connection between blocks *17* and *18*, and makes connection between blocks *17* and *19*, leaving block *18*, which connects to the No. 2 motor, hanging in the air so that no current can get to the motor. When the current gets to block *17*, instead of taking the path *18*–*12*–*11*–$F_2+$

$-F_2+ -F_2+ -F_2- -F_2- -F_2- -A_2- -A_2- -A_2- -A_2+$, thereby passing through the No. 2 motor to the ground wire at *G*, it passes across the metal strip, indicated by the dotted line, to block *19* and thence to the ground-connecting post *G*, into which the regular car ground wire goes. The path of the current, then, on the first notch, when the No. 2 motor is cut out, is $W-K-K-F.B.-T-a-a_1-R_1-R_1-R_2-R_3-R_3-M-X-13-14-9-F_1+ -F_1+ -F_1+ -F_1- -F_1- -F_1- -A_1+ -A_1+ -A_1+ -A_1- -A_1- -15-16-R_4-R_4-R_5-R_5-c_4-c_2-8-6-b_2-b_3-7-17-19-G$. It must be borne in mind that only one cut-out plug can be turned at a time, and that the dotted lines indicate the path of the current through a cut-out only when the motor operated by that particular cut-out plug is actually cut out by giving the plug a quarter-turn. In tracing the path of the current under any condition, then, it must be understood, that if both motors are cut in, the dotted lines representing the short-circuiting strips must be ignored; but if one motor is cut out, the dotted line on the cut-out which operates that motor, represents the path of the current through *that* cut-out, while the current still uses the vertical full line on the motor that is not cut out. The idea of a dotted line in such a case is to indicate some alternative position of a moving part. The part cannot, of course, be in both positions at the same time.

**48. General Remarks on 28A Controller.**—It will be noticed that in the 28A car wiring, there are 14 wires running from one end of the car to the other; they are designated as *T*, $R_1$, $R_2$, $R_3$, $R_4$, $R_5$, $F_1+$, $F_1-$, $A_1+$, $A_1-$, $F_2+$, $F_2-$, $A_2-$, and $A_2+$ or *G*. Each one of these wires goes from a marked connecting post on one controller to a connecting post of the same name on the other controller, bearing in mind, of course, the exception, that either both field wires or both armature wires are reversed, so that the position of the reverse switch will correctly indicate the direction in which the car will move when the power is turned on. For example, the No. 1 controller car wire would be marked $A_1+$ on one end, but $A_1-$ on the other; or, if the fields are selected for reversal, the No. 2 motor-field car wires would

go into the $F_2+$, $F_2-$ posts on the No. 1 controller, but should go into the $F_2-$, $F_2+$ posts on the No. 2 controller; so would the field car wires on the No. 1 motor be reversed on the No. 2 controller. The 14 car wires can be thus explained: The $T$ car wire runs from $T$ on one controller to $T$ on the other, and the wire from the hood switch, via the fuse box, splices on to it wherever it is most convenient to do so; according as one controller or the other is used, so is the car wire on one side or the other of the splice. The $R_1$, $R_2$, $R_3$, $R_4$, and $R_5$ car wires are all resistance wires and all run from one end to the other and between controller connecting posts of the same name. The large starting coil and the small starting coil together make a 3-part starting coil, and ordinarily to connect up a 3-part coil only four car wires are required, because when the several sections of a starting coil are all in a row, each car wire taps on to the end of one section and the beginning of the adjacent section, as shown in Fig. 29 (*a*); but if the several sections of the coil are in different parts of the circuit (in two parts in this case), more car wires are required, as shown in Fig. 29 (*b*). There is no apparent advantage in connecting them so. $A_1+$, $A_1-$, $A_2-$ are armature wires; $G$ and $A_2+$ are one and the same wire, because one armature lead is spliced on to the ground wire. $F_1+$, $F_1-$, $F_2+$, $F_2-$ are field car wires, the number telling to which motor it belongs.

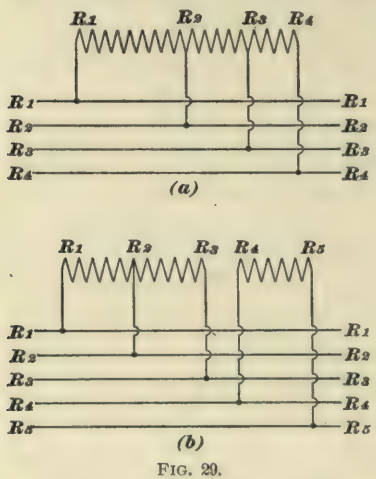


FIG. 29.

**49.** All car wires are enclosed in a hose, constituting what is called the **cable.** As in the case of the K2 and K11 General Electric controllers, the motors are numbered one

and two, so that a person standing on one end of the car is nearest the No. 1 motor, but on the other end of the car he is nearest the No. 2 motor. This causes some confusion in the motorman's mind when he wishes to cut out a motor, for he must find out which is the No. 1 motor, before he can decide which cut-out switch to use. As a matter of fact, the average motorman will have no rule, but will try one cut-out switch, and if that does not work, try the other one, with the result that he very often does more damage than the fault has done. The rule usually observed in wiring a car and numbering the motors is to call the motor on the fuse-box end of the car the No. 1 motor; this motor can then be cut out by means of the lower cut-out plug.

**50.** Another way to simplify the cutting out of a motor, is to so wire the controllers that, irrespective of the end of the car upon which a person may stand, the lower plug will cut out the motor nearest to that end, and the upper plug, the motor farthest from that end; to do this, the No. 1 controller is wired just the same as before, but in connecting the car wires to the No. 2 controller, the wires marked $F_1+$, $F_1-$, $A_1+$, $A_1-$, are put into the connecting posts marked $F_2+$, $F_2-$, $A_2+$, $A_2-$ or $G$, and vice versa; the wires marked $F_2+$, $F_2-$, $A_2+$, $A_2-$ or $G$, are put into the connecting posts marked $F_1+$, $F_1-$, $A_1+$, $A_1-$; in other words, the No. 1 motor car wires are run to the No. 2 motor posts and the No. 2 motor car wires are run to the No. 1 motor posts. With this condition of things, it is only necessary to remember that the bottom plug cuts out the motor nearest the end of the car in use, whatever end that might happen to be; it is then unnecessary to find out which is the No. 1 motor. This change in the wires must, of course, be made by a man who knows his business, or there may be trouble. One effect, incidental to such a change, is to reverse the relative positions in the circuit of the two motors, when going from one end of the car to the other; that is to say, on one end of the car the current from the trolley will reach the No. 1 motor first, but on the other end the No. 1 motor is next to the rail.

GROUNDS.

**51.** As on all other systems of control, the symptoms caused by **grounds** in the wiring or in any device depend a great deal on where the ground shows up; a ground anywhere from $W$ to the negative side of $F.B.$ (not very apt to occur anywhere except in an iron-girdered house or under an elevated-railroad structure, where the pole sometimes slips off and gets twisted into such a shape that it can touch the trolley wire and a part of the iron structure at the same time) results in burning off a part of the trunk wire, or a switch blade, if it happens to make poor contact, unless the station breaker acts promptly.

**52.** A ground anywhere between the negative side of $F.B.$ and the finger $T$, or on finger $T$ itself, will cause the fuse to blow, and a new fuse cannot be put in unless the ground is removed or the pole held down.

**53.** A ground on the top drum casting ($a$, $a_1$, etc.) on finger $R_1$, or on car wire $R_1$, $R_4$, will cause the main motor fuse to blow as soon as the drum is turned to the first notch; in most cases, fingers $T$ and $R_1$ and casting tips $a$ and $a_1$ burn so badly, as soon as they touch, that the drum cannot be forced to the first notch. In case the ground proves to be on the drum casting, it can have no effect as long as the drum is at the off-position, so that in such a case the car can be run from the controller on the other end; but a ground anywhere on $R_1$, $R_4$ must be removed before the car can be operated from either end, because the affected wire runs into both controllers and it is not in the part of the circuit that can be cut out by means of either cut-out plug.

**54.** A ground in between finger $R_2$ and block $R_3$, whether it be on the starting coil itself or on the wires, has the same general symptoms as the above, but may be a good deal less violent on account of a part or all of the large starting coil being in circuit.

**55.** A ground anywhere from finger $T$ to block $R_3$ is apt to do a great deal of harm by burning, because the blow coil $M$ is not in circuit to put out the arc.

Whether the ground is on the positive side or whether it is on the negative side of the blow coil *M* can be easily told by the character of the noise that the arc makes; if the ground is on the positive side, the arc will last longer and will have a long drawn out and sawing sound; if on the negative side, the blow coil will be in circuit, there will not be so much smoke and flame, and the noise will be of a sharp sputtering nature. The blow-out coil gives more trouble from grounds than any other part of the 28A controller, but is easy to fix.

**56.** A ground from *X* to block *13* inclusive, or on the wire running from the splice on wire *X–13* to fingers *4* and *5*, will render the car helpless and the controller will flash badly when thrown on and off; but as the large starting coil is in ahead of it, the main motor fuse may not blow until the drum is turned beyond the first notch and some of the large coil cut out. Such a ground is felt on both ends of the car, and the car cannot, therefore, be started until the fault is removed. A ground in any of the above named places has this peculiarity—that it cannot be cut out by means of either of the cut-out switches; it must be gotten rid of before the car can be run from that end.

**57.** A ground on block *14* or anywhere in the stretch of circuit *14–9–*$F_1+-F_1+-F_1+-F_1--F_1--F_1--A_1+-A_1+-A_1+-A_1--A_1--15$, can be cut out by means of the lower plug, and what symptoms it will cause depends on where it is and

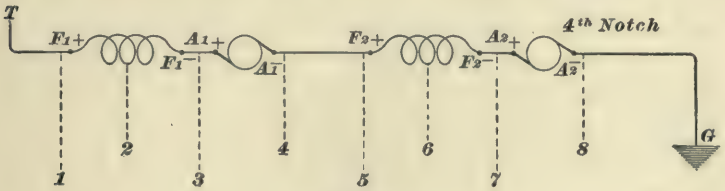



FIG. 30.

when it shows up. The effect of a ground from block *14* to block *15* can be more clearly seen by the aid of Fig. 30, which is a diagrammatic sketch of the circuit that the current travels on the fourth notch; what is true of the fourth notch, is

true of the first, second, and third notches, except that the action of the car is apt to be less violent, since there is more or less of the starting coils in circuit, and the blow-out coil is also in action. It will be borne in mind, when looking at Figs. 28 and 30, that the armatures are now next to the ground. On the K2 and K11 wiring diagrams, the fields were next to the ground; this affects, to some degree, the actions and symptoms under certain conditions. In Fig. 30, the stretch of circuit from $T$ to $F_1+$ is the same as in Fig. 28, only the intermediate letters and numbers have been left out. The effect of a ground is, in general, to blow the main motor fuse and make the car a cripple until the fault is gotten rid of. A ground within the field winding itself (indicated by dotted line No. *2*) will, it can be seen, cut out all of the car wiring beyond the fault; if the fault happens to occur while the car is at rest, or if it may have been turned into the house and no one's attention called to its condition, it will, on trying to start, give the same symptoms as if the fault were between $T$ and $F_1+$. If the fault occurs while the car is in motion, the motor will buck and cause a halt in the speed of the car, because that part of the field that lies between $F_1+$ and the fault becomes separately excited, and its armature is able to generate a current of its own, using the No. 2 motor, the permanent ground $G$, and the fault ground *2* as a local circuit.

**58.** A ground at *3*, on the negative side of the No. 1 field, amounts to the same as a ground on the $A_1+$ armature lead or car wire or any block or finger connected directly to it, and causes the car to act the same as if there were a ground at *2*. Since, however, the whole of the No. 1 motor field is separately excited, the motor bucks more violently and the car's speed gets a more powerful check. A ground at *4* allows the current from the trolley wire to take the path $T$–$F_1+$–$F_1-$–$A_1+$–$A_1-$–*4*, thereby getting to the ground without going through the No. 2 motor at all, so that as long as the motors are in series the car can start on one motor and run on one motor, the fault at *4* or *5* cutting the No. 2 motor out. The stretch of circuit $A_1-$–$F_2+$, in Fig. 30, corresponds

to the stretch of circuit *16*–$R_4$–$R_4$–$R_5$–$R_5$–$c_4$–$c_2$–*8*–*6*–$b_2$–$b_3$–*7*–*17* in Fig. 28, and like the stretch from *T* to *13*, cannot be cut out by means of either of the plugs.

**59. Grounds on No. 2 Motor.**—As has been said before, one end of the No. 2 motor starts at block *18* and the other end goes to the ground, so that the No. 2 motor can be cut out of action by turning the No. 2, or $L_2$ plug, thereby cutting it off at the end from which it gets its current. A ground at *6* will excite a part of No. 2's field and a ground at *7* will excite all of its field, and, as in the case of the No. 1 motor, enable it to buck if the fault occurs while the car is in motion on the series notches. If the fault shows up while the motors are in multiple, and each motor has a circuit of its own, the motor not only bucks violently, but the main motor fuse blows, because the trolley current has a direct path to earth through the faulty field, and there is no ohmic resistance or counter E. M. F. in circuit with it to limit its value.

A ground at *6* or *7* will cause a car to start with a kind of drag, as if it were hauling a heavy load, and as a matter of fact, this is exactly what it is doing. As soon as the current is turned on, it passes through the starting coils and through the No. 1 motor, on through the fault in the No. 2 motor field to the earth; the No. 1 motor and its circuit being in good order, the motor can start the car alone, just as it would do were the No. 2 motor cut out by means of its plug instead of being cut out through the fault in its field; but as soon as the No. 1 motor takes a current, so does the No. 2 motor field, thereby becoming separately excited, and as soon as the car begins to move, the No. 2 armature begins to generate a large current through the short circuit established by the fault on one side and the permanent ground on the other, and the faster the car tries to move, the larger is the current generated by the No. 2 armature. A ground at *8* can have no effect on the action of the car, because this side of the circuit is already grounded through the permanent ground at *G*, and it cannot be any more so by a fault.

**60. Power Drum and Reverse Switch.**—A ground anywhere on the *b* or *c* castings of the power drum makes itself felt as soon as the drum is put on the first notch; but as it is not in circuit at the off-position, the car can be run from the other end. A ground on either of these castings is not apt to do any serious harm if handled with judgment, because not only are both starting coils in the circuit, but so is the blow-out coil. A ground on the *d* casting will not ordinarily be felt until the drum reaches the sixth position, and since the casting is virtually used as a ground casting, it is not very apt to give a great amount of trouble.

# CAR EQUIPMENT.

(PART 9.)

## THE WALKER SYSTEM.

**1. Walker Motor.**—The life of The Walker Company as an independent concern did not last long enough for its motors to become as widely adopted as their good qualities under the test of time would merit. The Walker Company, so far as its motors are concerned, passed through no experimental stage; the other companies did the experimenting and they engaged their well schooled engineers. The result was a first-class street-car motor that stands on its merit. The Walker Company has made many sizes of railway motors, from 20 horsepower to 200 horsepower for train work, but this section will be confined to a consideration of their 25 and 30 horsepower motors.

### WALKER 30-HORSEPOWER MOTOR.

**2.** The Walker 30-horsepower motor is shown in Figs. 1, 2, and 3, where the motor is shown both closed and open. The general shape of the motor, as seen in Fig. 1, is six-sided.

**3. Frame.**—The frame of this motor is really in three parts: the top and bottom field shells and the yoke *F*, Figs. 1 and 2. The main-motor shell, as on all up-to-date motors,



For notice of the copyright, see page immediately following the title page.

is of low-carbon steel, and is cast in two halves, each half

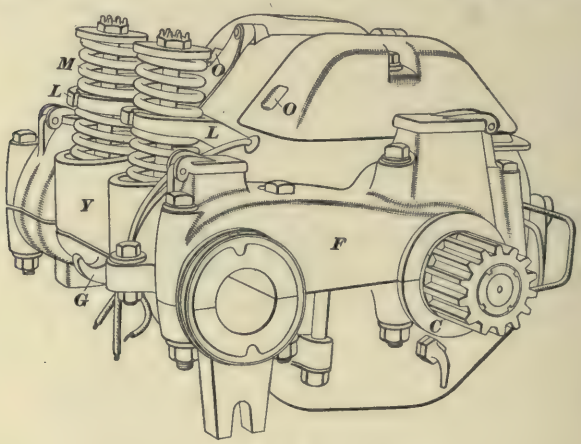



FIG. 1.

having cast with it two pole pieces projecting radially inwards. The axle-bearing caps are on the under side and the axle

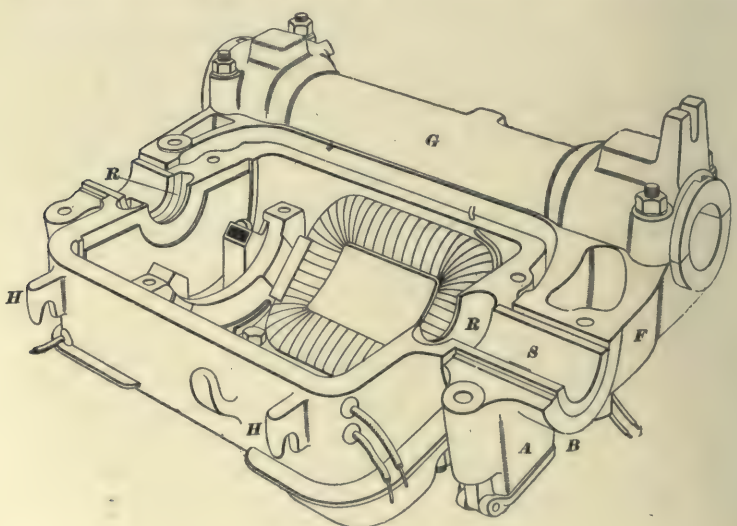



FIG. 2.

gets its grease from grease cups that are on top. In Fig. 2, at *H*, *H*, are shown two lug hooks that serve two purposes:

they act as hinges upon which the lower shell can be swung to and open, and also, by means of an eyebolt and nut, not shown in the figure, serve to draw the two halves of the shell tightly together. These two eyebolts and hinges,

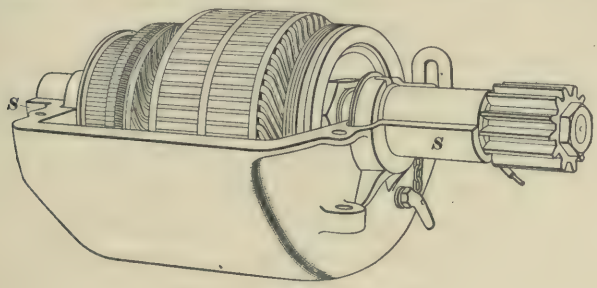



FIG. 3.

together with two more bolts on the opposite side of the motor, are all that hold the two halves of the motor together; but as the bolts are amply large and the lower half of the shell is very light, nothing more is needed.

To make inspection easy and to facilitate blowing out the inside of the motor with an air blast, where such a convenience is to be had, the top shell has a door over each end of the armature. The door on the commutator end being more frequently used for inspection and renewal of brushes, is made to open on hinges. The door on the pinion end is secured with a bolt, and must be lifted off. Besides the openings on top of the shell, there is a handhole in the bottom shell just beneath the commutator; this opening is used to test, by means of a gauge, the air gap between the armature and the lower pole pieces; it can also be used to remove broken brushes and whatever nuts, lock-washers, or other foreign substances chance to fall into a motor while working on it. Such things, when they do get into a motor, generally do so without the knowledge of any person; but whether any one knows it or not, the article in question always manages to crawl into some hole that cannot be reached from the openings in the top.

When such is the case, the chances are that nine out of

every ten men, rather than burn their wrists on a hot commutator, or open up the motor to get the article out, will let the car go, and run the chances of having the bolt or nut, or whatever it may happen to be, rub the band wires off the armature and ground the coils. Some idea of the number of times that pieces of foreign matter get in between the armature and the pole pieces can be formed by looking at the inspection sheets on roads that run motors with laminated pole pieces; or, better still, look at the motors themselves. After one year of use, five out of every ten motors inspected will have the polar surfaces marred in one way or another. The plates in the pole faces will be twisted or bent aside, and, in some cases, even have pieces broken out. The face of such a pole piece being mechanically weaker than the surface of the core, serves as a sort of mechanical fuse to save the armature core from perhaps a more serious injury.

**4.** To further lessen the chances of the armature getting down on the pole pieces, the Walker motor is provided with a plugged peep hole on both ends of the motor, in line with the air gap between the armature and the two bottom pole pieces; by taking the plugs out of these holes, holding a light up in front of one hole and looking into the other, one can see at a glance how much clearance there is between the armature and the pole pieces. If the clearance is not enough, the armature bearings must be renewed.

**5.** One very unique feature about the Walker motor is the attempt made to ventilate the inside of the motor. The problem is to let the air into the motor and out of it without letting any water in. The problem has been solved by providing each of the two top motor covers with vent holes *O*, *O*, Fig. 1. The holes are really the mouths of tubular channels whose inside ends are several inches above the outside ends. This construction admits air without letting in water. In the lower shell, the openings *R*, *R*, Fig. 2, are cast, letting the air in and out; this opening, in conjunction with the grease collars on the armature shaft, prevents any oil or

grease from getting inside the motor. The oil and grease are thrown out on to the track.

**6.** In Figs. 1 and 2, *F* constitutes what is called the *suspension arm* more commonly known as the *motor frame* or *yoke*. This yoke is not on the same lines as the yoke of the Westinghouse No. 3 motor, because on that motor the armature is supported independently of the motor shells, and any wear in the hinges throws the shells out of center, and, in course of time, unless the wear is taken up, the pole pieces are down on the armature. In the case of the Walker motor yoke, all parts are practically hung together, so that there is no chance of the pole pieces being thrown out of center as a result of wear in the hinges. The yoke on the axle side is cored out its full length, but is machined only on the two ends, where it receives the axle bearings. The yoke acts as the top axle-bearing cap, and hangs over the axle. The lower caps are replaced by a cast-iron half sleeve *G*, Figs. 1 and 2, which runs the full length of the yoke and is machined on the ends for the axle bearings, the same as the yoke.

In looking at Fig. 2, the student is apt to be confused by the fact that, from the position of the cut, it might easily be taken to represent the bottom half of the motor. Of course, the brush holder is a constant reminder that the cut must represent the top half; besides this, the grease cup *A* is upside down and this is not a very natural position. Fig. 2 shows the top half turned over. On each end of the top and bottom halves of the motor shells, is cast a hub *S*, *S*, *S*, *S*, Figs. 2 and 3. The two halves of the shell are clamped together; the outside of these hubs is turned down to fit the machined hole formed by the coming together of the yoke bearing *B* and its lower cap *C*, Fig. 1. The inside of the hubs is bored to fit the outside of the armature-bearing sleeves. The whole construction, then, constitutes a bearing within a bearing; the motor shells, as a whole, turn in the yoke as much as springs *M*, Fig. 1, will allow, and the armature turns in its own bearings in the hubs. The yoke *F* is of cast iron and on some roads gives trouble by breaking.

**7. Armature.**—Fig. 4 shows the general construction adopted on all Walker armatures. It is of the so called protected type, and has given general satisfaction. The Walker 25-horsepower armature belongs to the narrow-gauge

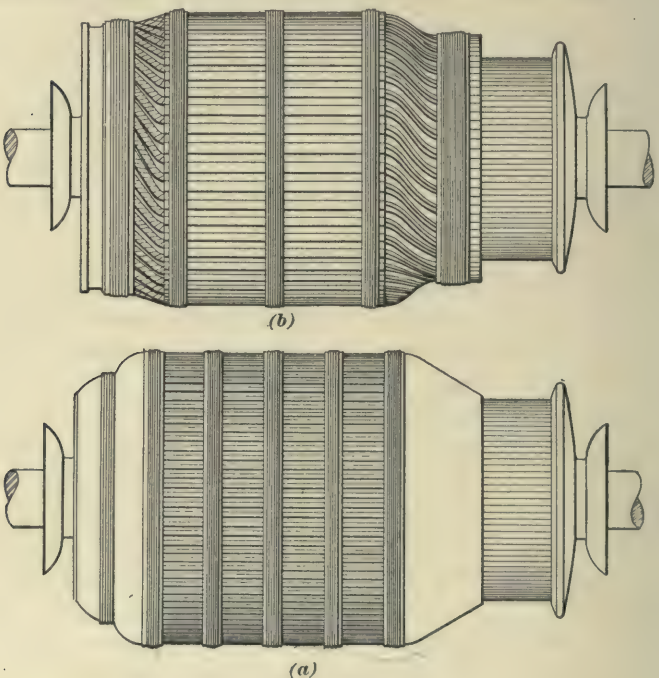



FIG. 4.

motor used very little in this country. The 30-horsepower armature is in general use and is a good one. It is a coil-wound armature with 97 slots in the core and 97 bars in the commutator, and, therefore, requires 97 coils to wind it. In Fig. 4 are given two types of Walker winding: (*a*) is the old style discarded; (*b*) is the new armored style.

The commutator has hard-drawn copper bars, and all the insulation is pure mica. The end of the shaft where the pinion goes on is tapered, as well as the commutator seat, so that either device can be drawn without pounding. The commutator ears on the Walker armature are extended so

that the diameter of the ear part of the commutator is nearly the same as that of the armature core. This is a feature that The Walker Company claims lessens the liability of the armature head and string band being burnt full of holes through the flashing of the brushes. Referring to Fig. 4 (*a*), it will be seen that the head is almost in line with the brush-surface contact, and is exposed to any flashing that may take place. In Fig. 4 (*b*), the head is dispensed with, but the string band does not run the same chance of being burned off, because the surfaces adjacent to the brushes are of the same potential as the brushes themselves, so that when the latter flare, due to abuse, neglect, a poor brush, a weak field, or any other cause, there is no tendency for the arc to travel to the head of the commutator. The raised ears are interposed between the string band and the seat of all the flashing, and form, so to speak, a metallic shield between them. It will be noticed that on the armature shown at (*a*), the coils turn down on the ends; on the new type, shown at (*b*), they run straight out; yet this new armature is no longer than the old one.

**8. Field Coil.**—The Walker field coils, when in position in the motor shell, at once appeal to the critical eye on account of their neat appearance and compactness. They are curved to fit the inside contour of the motor frame and they are curved on the outside also, as shown in Fig. 5. The result of this design is a coil that is graceful in outline and compact in form, so that it takes up very little room in the motor, but the coil is very much harder to wind than a straight coil. It takes longer to get around the curves, and so costs more. One very good point about the Walker field coil is that there is very little chance of connecting up a coil wrongly on account of not being able to tell one lead from another. One

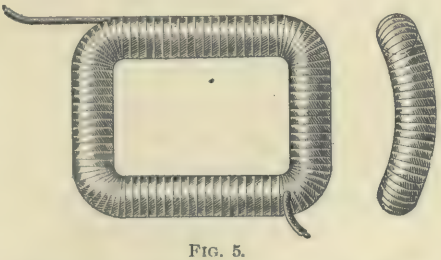


FIG. 5.

lead is brought out parallel to the direction of the winding and the other is brought out at right angles to this direction, and there can be no mistake about which is which. The only thing the pitman has to bear in mind is to connect together two leads that are alike. This is a rule that holds good on any street-car motor. There are four field coils to each motor, and each coil has in it $38\frac{1}{2}$ turns of No. 6 B. & S. gauge, double cotton-covered copper wire, making 154 turns per motor. The insulation on the coil is not heavy, but what there is of it is good. The Walker Company in all of its work seems to be very partial to the liberal use of good, clear mica. The field coils are held in place by brass castings, the general shape of which is shown in Fig. 6,

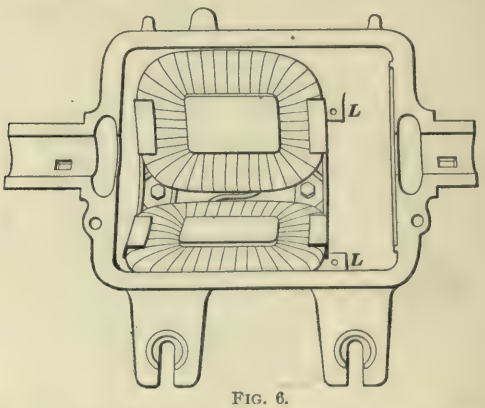



FIG. 6.

which is a view of a top shell. These *field plates*, as they are called, present a good surface to the field coil, so that there is no danger of cutting into the field insulation when the bolts that hold them are drawn home. The removal of four bolts frees four fields for removal.

**9. Brush Holder.**—The Walker brush holder is not a very elaborate affair and a general idea as to its construction may be obtained from Fig. 7. The holder shown is of the radial type, and employs a single brush on either side. In Fig. 7, $O$ is the center of the circle that represents the outline of the commutator; $OA$ and $OB$ are radii making an

angle of 45° with the vertical line *O C* drawn through center *O* and making an angle of 90° (one-fourth of a circle) with each other. If the brushes touch the commutator at the two points where lines *O A* and *O B* cut its circumference, then we may be sure that the holder is in a central position and that the brushes, since they include one-fourth of all the bars in the commutator, are at the right distance apart—two very important points to remember when setting brushes on any street-car motor. If the brushes are the right distance apart, but are not central, they will spark when the car goes

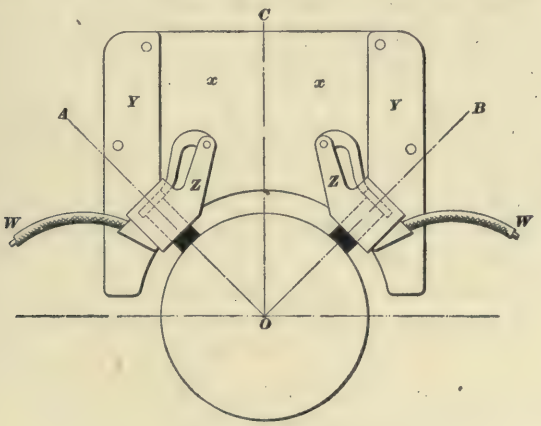



FIG. 7.

one way, but will not spark when the car runs the other way. If the holder is central, but the two brushes are not the right distance apart, the brushes will spark going both ways. In Fig. 7, *x* is a wooden or vulcabeston yoke hung to the top motor shell by means of bolts passing through lugs *L*, *L* shown in Fig. 6. *Y*, *Y* are reinforcements crossing the grain of *x*. *Z*, *Z* are the holders proper provided with a tension spring, not shown in the figure, to press the brush against the commutator, and with brass cups to which leads *W*, *W* are soldered. The brush has a radial adjustment and this is all that is needed. The spring that feeds the brushes is a very strong one, but the intervention of a lever moderates the intensity and increases the scope of the spring so

that, throughout the natural life of the brush, it presses upon the commutator with an almost uniform intensity.

**10. Bearings.**—The Walker axle bearings are iron sleeves, Babbitt lined, 8 inches long, and any diameter up to $4\frac{1}{2}$ inches; they are held in place by the sleeve *G*, Figs. 1 and 2, extending the full length of the yoke. The axle receives its lubrication from grease cups in the suspension yoke.

The armature bearings are also Babbitt-lined cast-iron sleeves with a flange on one end. The end of the flange is babbitted, and bears against the oil guard on both ends of the armature shaft, thus acting as a limit to the end play. In the flange of each bearing is tapped a hole that takes a bolt passing down through the yoke alongside of the grease cup. When dropping the lower shell, if it is desired to retain the armature in the top shell, this bolt (on both ends) is left screwed home; the armature then stays up, because the bolts hold the bearings and the bearings hold the armature. If it is desired to lower the armature in the bottom shell, the bolts are taken out.

**11. Gearing.**—The Walker gear is made of cast steel, and the pinion of cast steel or of hot-pressed iron; the gear has 67 teeth and the pinion 14, making a gear-reduction of $\frac{67}{14} = 4.78$. The pinion is taper bored to fit the taper seat on the shaft and is held by a spanner nut and lock-washer.

**12. Suspension.**—Suspensions in general will be taken up later, but a few remarks on the Walker suspension will not be out of place here, because the peculiarity of this suspension affects the mechanical design of the whole motor. The unique feature of the Walker suspension is that the motor is entirely spring suspended; the only weight that hangs dead on the axle is a part of the weight of the suspension yoke, and this is almost nothing when compared to the weight on the axle with the ordinary nose suspension in use. Any one that has seen the two motors on a car'act when the

car is started, knows that when the current is turned on, one motor jumps up and the other motor springs down. This is, of course, due to the pull of the armature on the pole pieces; the armature tries to pull the whole motor around with it, with the result that on one motor the top suspension springs are depressed and on the other motor, which is turned end for end, the bottom springs are depressed.

By looking carefully at Fig. 1, it can be seen that the motor shells are not rigidly fixed at any point. They are supported in two places as follows: (1) On the axle side, they are hung in between suspension springs *M*, *M* by means of lugs *L*, *L*, Fig. 1, cast as a part of the top shell. (2) The other point of support is the two hubs *S*, *S*, Fig. 3, which act as centers or bearings on which the two shells as a whole can turn in the frame *F*. The movement of the shell on these centers is limited by the amount the top and bottom suspension springs *M* can be compressed. The top spring limits the movement up and the bottom spring the movement down, the total movement, of course, being equal to the sum of the two. The motor being also supported by springs on the side opposite the axle, the same as in an ordinary nose suspension, there can be no reaction between the motor as a whole and the car axle, except through springs that cushion the effect of the blow. In the ordinary mode of suspension, one side of the motor is hung directly on the axle, without the intervention of any spring on that side; the axle therefore supports one-half the weight of the motor as a dead weight, and the whole structure gets a blow every time the car rolls over a frog crossing or a rough piece of track. This continual pounding is not only hard on the truck, track, and axle, but in course of time shakes the motor bolts loose and shakes the gear-case out of adjustment.

**13.** Fig. 8 is a Walker suspension. It does not show the method of hanging one of the latest type motors, the motor in the figure being one of the earlier Walker types, but the principles involved are the same, and the figure

shows clearly the method of supporting the motor on the side opposite the axle, and also shows the strong eyebolt construction at *I* for swinging the lower shell and for holding the two shells together. *B* is a bar running from one side of the truck to the other, and is called a *suspension bar;* it is supported on the two side members of the truck through the intervention of the springs *S*, *S'*, called *suspension springs;* when, in starting, the motor throws up, spring *S'* is compressed; when the motor throws down, spring *S* is compressed. In ordinary running over rough track, the motor jumps up and down, and first one spring and then the other

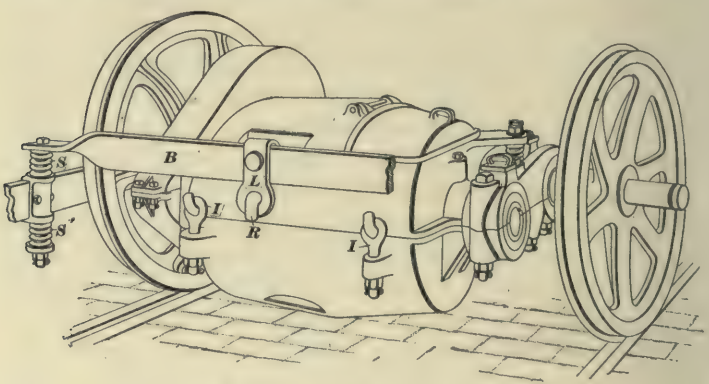



FIG. 8.

is in action. In order to avoid any rattling noise in the springs, the bolt that holds them should, when the motor is at rest and the car standing still, have its nut screwed down until both springs are under a good compression; otherwise, when the weight of the motor for any reason acts with force enough to close the top spring, the bottom spring will rattle, giving forth a noise which, if the gear-case happens to be loose and rattling at the same time, will lead the general public to believe that the whole car is about to go to pieces. *R* is called the *suspension hook*, and is cast to the top motor shell. *L* is the *suspension link.* It engages the suspension bar on one end and the suspension hook on the other end, and is fixed to the bar with a bolt or rivet.

## WALKER TYPE S CONTROLLER.

**14. Type S Controller.**—The last and the best controller put on the market by The Walker Company, Fig. 9, was the type S, which had several unique features. The most important new feature and the one from which it takes its name, "S" being the initial letter, is the device for blowing out the arc. This device is called a **solenoid,** hence the name solenoid controller or S controller. (A solenoid is another name for a piece of wire wound into a spiral. Take a piece of magnet wire, wind it on a lead pencil, then withdraw the pencil and the wire is left in the shape of a solenoid.) Fig. 10 shows how the solenoids are arranged between the contacts; *A* is a drum contact and *B* one of the fingers. The arcs

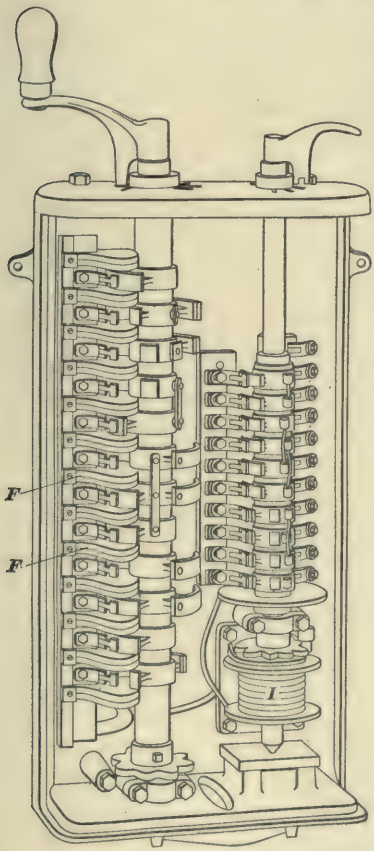



FIG. 9.

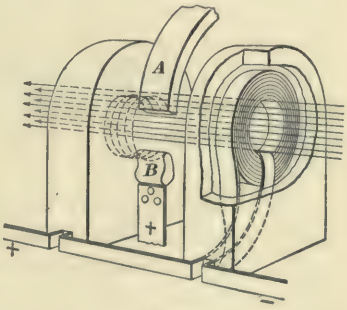



FIG. 10.

are blown out by the magnetic lines of force due to the passing of the current through coils or solenoids of flat copper ribbon, which are embedded in the partition separating the several fingers of the power drum. The magnetic lines

of force are so directed that they blow the arcs outwards, as indicated by the dotted curved lines, at right angles to the drum shaft, thereby avoiding the insulating bridges, so that the latter do not become chipped and charred.

The type S controller is, then, really a magnetic blow-out controller. As there is no iron in the solenoid, it is claimed that there is no danger of the current trying to jump through to ground. The whole number of magnetizing coils being divided up among the several solenoids, the self-induction of each solenoid is low, so that any of them can be cut out of circuit at any time they are not needed. This effects a small saving in power and saves the blow coils, because they can be cut out of action on the running notches. A coil with an iron core is kept in the circuit all the time, for if it is cut out on those notches in which it is not used, it does not have time, when it is cut in again, to build up a strong enough magnetic field to put out the arc before it has done some damage. Also, where a blow-out coil having much self-induction is cut out and into the circuit, the finger that does the cutting in and out generally gives a good deal of trouble from burning, because the arc is made to hang on by the self-induction of the coil, just as the arc hangs on when the field circuit of a shunt motor or dynamo is broken. The disposal of the solenoid is such that free access to the drums is not at all impeded. It is claimed that the addition of the blow-out device does not in the least complicate the controller, and it does, beyond a doubt, make the contact tips and fingers last longer.

**15. Reverse Switch.**—The reverse switch has seven notches; two are the ordinary "ahead" and "back" notches to be found on any controller; four are for running the car ahead and back on one motor when the other motor is cut out; the seventh notch is for an emergency stop. To apply it, the power handle is thrown to the off-position, and the reverse handle is thrown to the notch marked *Emerg.* On this notch, both motors are turned into dynamos, and send a current through a part of the starting coil; a load being thus

put on the car, and there being only its headway to support the load, the speed is checked. Fig. 11 shows the layout of the type S controller top. Both the power and reverse han-

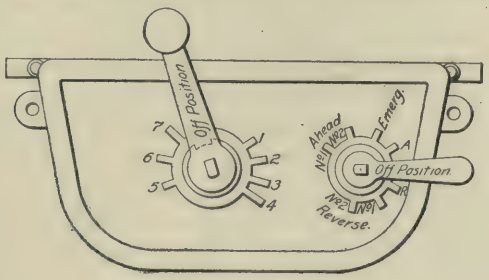



FIG. 11.

dles are at the off-position. There are seven points on the controller power drum. On four of these notches, the motors are in series; on *5*, *6*, and *7*, they are in multiple.

**16. Interlocking Device.**—Fig. 12 shows the type S interlocking device. In Fig. 9 it is shown in position at *I*. For reasons already stated, it is a good thing on controllers of any kind to have the two drums so interlocked that the reverse handle cannot be thrown over unless the power drum is at the off-position. On the type S controller, the interlocking of the drums is electromagnetic; the reverse drum is locked, whenever current is passing through the controller, by means of an electromagnetic device, which makes it necessary that the power drum be thrown to the off-position before the reverse handle can be moved; but at such times as the controller may not be in use, the handles can be turned freely in any way that may be desired.

The reverse drum is made to center itself in line with its contact plates and fingers by means of the usual spring-actuated roller and star wheel shown at *R*, *R*, Fig. 12. If the roller is locked, the reverse drum must be locked also; the arm *S* on which the roller is mounted carries an extension, not shown in the figure, shaped in the form of an eyelet, which, when the roller is in the trough of a notch, falls in line with a hole in the center of the solenoid, through whose

winding the main current must pass. An iron core or plunger is placed in an unstable position in the solenoid, so that when the latter carries any current, the plunger is sucked up into the eyelet on the roller arm, thus, in a positive manner, locking it, so that it cannot be moved until the power drum is thrown to the off-position, the current ceases to flow, and the plunger, having nothing to hold it, drops back into its normal position and releases the roller arm. The student must not get the solenoid here spoken of in connection with the locking device confused with the solenoids used to blow out the arcs on the power drum. They have nothing to do with each other whatever, and do not even look alike. One is hidden and the other is in plain sight under the reverse drum.

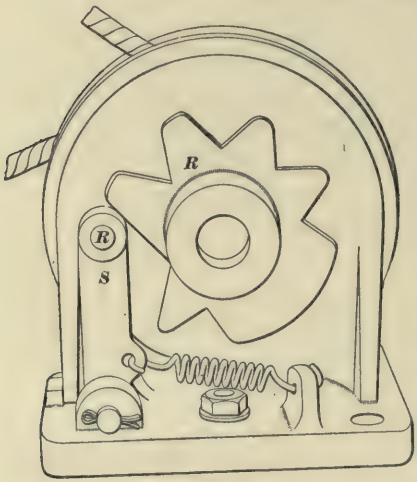


FIG. 12.

**17. Power Drum.**—Fig. 13 is a diagram of the type S power drum; the vertical dotted lines show the several positions passed through in the drum's course from the off-position to the last position in multiple. All the positions, however, are not notches. There are three castings on the type S power drum; each casting has several rings or tips. All the tips marked *a* in the figure belong to the *a* casting, and are connected together through the body of the casting. All the *b* tips are connected together, and also all the *c* tips; but the separate castings do not come in contact with each other until the power drum is turned to one of the on-positions, when the separate castings then come in connection through the internal and external wiring of the controller,

and through the motors, etc. It will be noticed that the $a_{4\frac{1}{2}}$ and $a_{9\frac{1}{2}}$ tips are narrower than any of the others. These tips are used for cutting the solenoid blow-out coil out of action on the last notch series and the last notch multiple. $a_{4\frac{1}{2}}$ is the tip that cuts out the blow coil on the series notch; if this tip were as wide as the $a_4$ tip, the drum would pass from the last series-notch without the blow coil being in, and there would be a great deal of burning. To avoid this, the $a_4$ tip is made to extend out a little farther than the $a_{4\frac{1}{2}}$ tip, so that the drum, in passing from series to parallel, leaves the $a_{4\frac{1}{2}}$ finger a little before it leaves the $a_4$ finger, and thereby cuts the blow coil into action again. The $a_{9\frac{1}{2}}$ tip cuts the coil out on the last multiple notch; the $a_9$ tip is a little wider than the $a_{9\frac{1}{2}}$ tip, so that when the drum is thrown to the off-position, the $a_9$ finger hangs on to its tip a little while after the $a_{9\frac{1}{2}}$ finger has left the $a_{9\frac{1}{2}}$ tip. The blow coil is thereby put in action. It is an open question as to whether it is a good thing to cut the blow coil out on the running notches or not. It is true that the blow coil is saved a great deal of heating by so doing, and it can be wound with a smaller wire than could be used if it had to stand the main-motor current all the time; also, the heat in the coil represents just so much waste of power, so that when the coil is cut out, the car is operated at a greater efficiency. On the other hand, experience has shown that the finger and tip used in cutting out the coil give more or less trouble from burning, due to the self-induction of the blow coil making it impossible to either make or break a current through it in an instant.

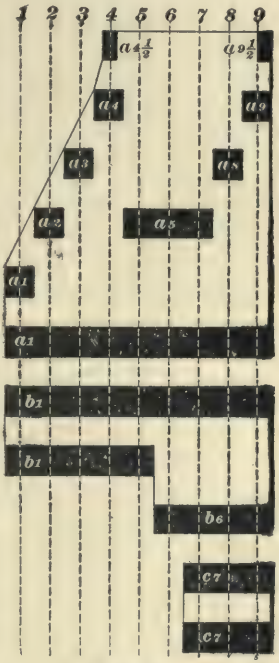



FIG. 13.

**18.** Fig. 14 (*a*) and (*b*) will help give an idea as to why this is so. In Fig. 14 (*a*), there are 5 rows of lamps, 5 lamps per row, across a 500-volt street-railway circuit. Now, if a

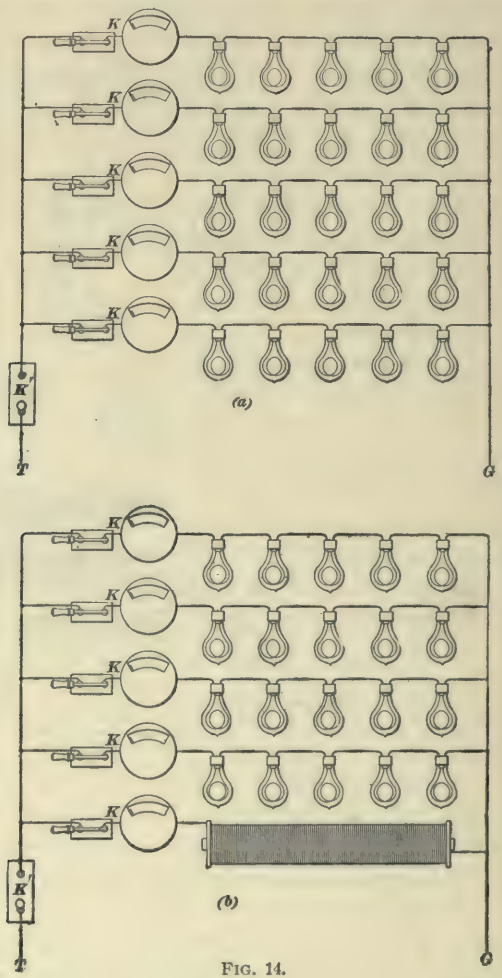



FIG. 14.

meter for measuring current be put in each row, as at $K$, as soon as the line switch is closed, all the lamp circuits will take a current of about $\frac{1}{2}$ ampere, and they will all take this current in practically an instant; also, any one of the lamp

circuits can be opened, and there will be no arc to speak of. In Fig. 14 (*b*), however, one row of lamps has been replaced by a coil of wire having an iron core, so that the self-induction is high; upon closing the line switch this time, the meters in the lamp circuits will at once register full value, but the needle of the meter in circuit with the coil will be seen creep up to full value slowly, although the ohmic resistance of the coil may be the same as that of a lamp circuit. This is because the current has to fight its way against the self-induction of the coil. This goes to show why the blow coil might not be ready for business soon enough when the power drum is operated rapidly. Again, when the coil circuit is opened at *K*, quite a long arc is seen; this is also due to the self-induction of the coil.

To get a good idea of what this self-induction amounts to, open the circuit on the whole device by opening the switch at *K'*. In this case, the voltage due to the self-induction of the coil will discharge itself through the four rows of lamps; if the induction coil used is strong enough, say as strong as the fine-wire field on a 500-horsepower dynamo, the lamps will jump far above the brilliancy with which they burned on the regular line voltage, and the lamps may even be all blown up by the discharge. As a matter of fact, the voltage due to the discharge of a large dynamo field is so great that some means is always taken to discharge the field slowly or to divert the discharge through some path that it cannot injure, otherwise it would pierce through the insulation of the dynamo field or armature. All this goes to show that a blow-out coil that is strong enough to do any good, cannot be cut into or out of action in an instant. It is true that the blow coils have but a few turns of wire in them, and, in this case, the coil has no iron core to intensify the inductive action; but, nevertheless, if the coil is strong enough to put out the arcs, it is also strong enough to have, to some degree, the bad effects spoken of above. It is a much safer, simpler, and more satisfactory plan to make the coil large enough to stand the main-motor current all the time; then there can be no burning.

In Fig. 13, the tips are so numbered as to show the position in which they come into action. $a_1$, $a_1$, $b_1$, $b_1$ go into action on the first notch; $a_5$ and $a_7$ tips go into action on the fifth and seventh positions, respectively. The blow-out coil cut-out tips are given the half numbers, because they have no position of their own.

**19. Internal Connections.**—Fig. 15 is a diagram of the internal connections of the type S controller. $S$ is the blow coil or solenoid, which is connected to both fingers $T$

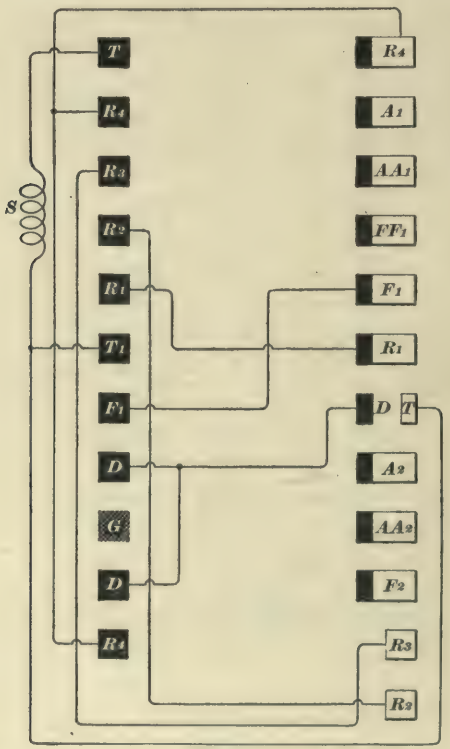



FIG. 15.

and $T_1$. There are 11 fingers on the power-drum side and 10 on the reverse-switch side. Only 8 of the fingers on the reverse switch are used in the reversing or in cutting out a

motor; but the two middle extra fingers take part when the reverse handle is thrown to the emergency position, to make the motors generate.

**20. Combination Cut-Out, Reverse Switch, and Emergency Brake.**—Fig. 16 shows the combination cut-out, reverse switch, and emergency-brake switch used on

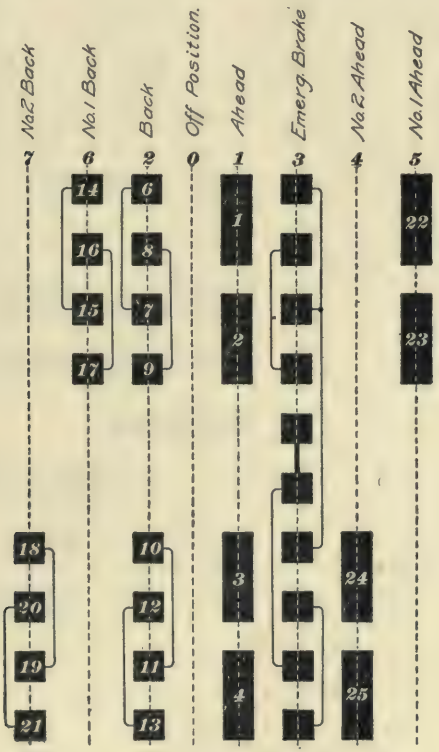



FIG. 16.

the type S controller and operated by means of the reverse lever.

On the first position, both motors are in circuit and the car moves ahead; on the second notch, the two motors are still in, but the car backs up. Take notice that the No. 1 and No. 2 positions are on opposite sides of the reverse

switch; also that the back-up position and the emergency-brake position are on opposite sides of the go-ahead position, so that it does not make any difference which way the motorman moves his reverse handle in time of trouble, he moves it to a notch that will stop the car. Of course, if he throws

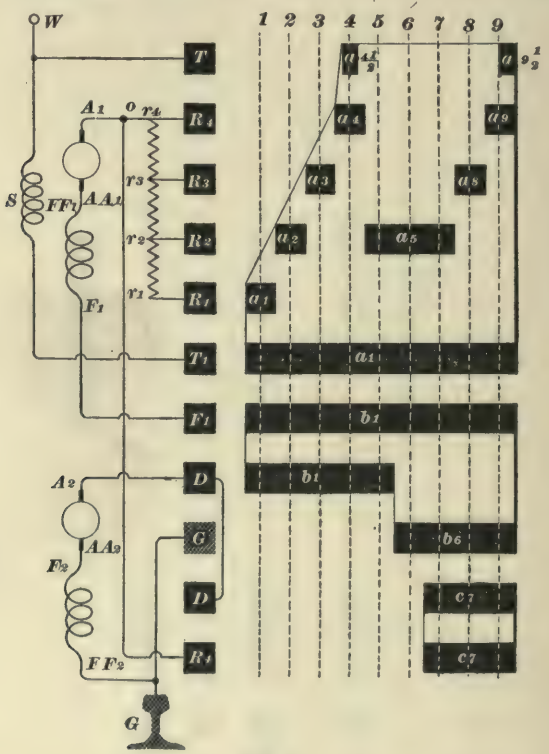



FIG. 17.

the handle back to the back-up position, he must put the power drum on again in order to stop the car.

Another important point in regard to the two notches is this: In using the reverse, or back-up, notch, the hand-brake must not be used after the motors have been reversed, because it holds the wheels so that the motors cannot turn them around readily, and cannot, therefore, back the car, unless the power drum is moved around to a notch where

the current gets so great that there is danger of blowing the main-motor fuse and thereby making the car entirely helpless. When the emergency-brake notch is used, however, the hand-brake can be applied to a great advantage, as soon as the motorman has tended to the setting of his reverse lever on the emergency notch, because the hand-brakes apply the shoes to the wheels, but the emergency brake does its work on the motor armatures themselves. A certain braking pressure applied to the armatures has much more effect than the same braking power applied to the wheels, because the pinions on the armatures exert their force with the long end of the lever, while a force applied to the car wheel must act on the short end of the lever. On the fourth notch, the No. 1 motor is cut out and the car runs ahead on the No. 2 motor. On the fifth notch, the No. 2 motor is cut out and the car runs ahead on the No. 1 motor. On the sixth notch, the No. 2 motor is still cut out and the car backs up on the No. 1 motor; while on the seventh notch, the No. 1 motor is cut out and the car backs up on the No. 2 motor.

**21. Simple Wiring Diagram Without the Combination Cut-Out Switch.**—Fig. 17 is a car-wiring plan with the motor cut out, reverse switch and brake device left out, and the wires run direct, so that it can be easily seen where such devices are cut into the circuit. In Fig. 17, *S* is the solenoid or blow-out coil; it is shown here, as it is always shown in car-wiring diagrams of the type S controller, as a single coil; but, as a matter of fact, there are several blow-out coils; they are embedded in the thick vulcabeston partition rings that separate the fingers from each other. These partitions are shown in Fig. 9 at *F*, *F*. The advantage claimed for this construction is that each blow coil is used only when the fingers whose arcing it is intended to put out, are used.

In Fig. 17, the position of the blow coil in the circuit is such that it must carry a current whenever the controller carries one, unless the power drum happens to rest on a notch where the blow coil is intentionally cut out. The

figure shows correctly the idea, however, in so far as it is a fact that the blow coils are all cut out on the series and multiple running notches. $W$ is the trolley wheel, and, ordinarily, the current must pass through the blow-out coil and go into the power drum through finger $T_1$; but on the fourth notch series, the $T$ finger makes contact with tip $a_{4\frac{1}{2}}$, and on the ninth notch, this finger makes contact with the $a_{9\frac{1}{2}}$ tip, so that the current, instead of going through the solenoid at $S$, passes straight to finger $T$ and into the drum on that finger, thereby cutting the solenoid out. $r_1\ r_2\ r_3\ r_4$ is the three-part resistance coil, all of which is cut out on the fourth notch. $A_1$ and $A\ A_1$ are the terminals of the No. 1 motor armature, and $F\ F_1$ and $F_1$, the terminals of its field coil; $A_2$ and $A\ A_2$ are the No. 2 motor armature leads, and $F_2$ and $F\ F_2$, the No. 2 motor field leads.

When the power drum is thrown to the off-position, the circuit is broken in only four places: the $R_1$, $T_1$, $F_1$, and $D$ fingers. This is quite different from the earlier types of Walker controller, in some of which the current was broken in as many as twenty-eight places at once, and it shows that there is little doubt as to the effectiveness of the solenoid in blowing out the arc. The numbers at the top of the drawing show the positions of the power drum, all of which positions, however, are not notches. There are also two positions that are not numbered, but will be readily seen, when we trace out the path of the current on the several positions. The letters and numbers on the power drum are the same as those of Fig. 13.

**22. Current Paths and Combinations on the Several Notches.**—On the *first position*, which is the first notch, the path of the current is $W$–$S$–$T_1$–$a_1$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$r_4$–$A_1$–$A\ A_1$–$F\ F_1$–$F_1$–$F_1$–$b_1$–$b_1$–$D$–$A_2$–$A\ A_2$–$F_2$–$F\ F_2$ to the ground at $G$. It is thus seen that the field is next to the ground on both motors, and that the negative field lead on the No. 2 motor is permanently grounded to the motor frame. It must also be noted that the current goes into the single-letter ($A_1$) end of the No. 1 motor armature and into the double-letter ($F\ F_1$)

end of the field; when it gets to the No. 2 motor, it passes into the single-letter end of the armature, as it did on the No. 1 motor, but it also goes into the field at the single-letter end. In other words, the current enters the two motor armatures at the same end, but it enters the two fields at opposite ends. The reason for this has been already explained in connection with other controllers.

On the first position, then, the whole starting coil, the solenoid, and the two motors are all in series, and the same current passes through all of them. The first position is, therefore, a notch, but it is not a *running* notch; it is a *starting* notch. It is not claimed that the first notch is not a running notch, because the starting coil will be injured if it is used to run on, for The Walker Company claims that the coil is designed along such liberal lines that it cannot be hurt by such abuse, and that, therefore, every notch is a running notch; but the first notch is not a running notch in the true sense, because, since all of the starting coil is in use, the notch is not an economical one to run on; also, since the solenoid is in circuit and carries the main motor current, it becomes hot.

**23.** On the *second position*, drum tip $a_2$ makes contact with finger $R_2$ and cuts out of circuit that part of the starting coil that lies between $r_1$ and $r_2$, so the path of the current becomes $W$–$S$–$T_1$–$a_1$–$a_2$–$R_2$–$r_2$–$r_3$–$r_4$–$A_1$–$A$ $A_1$–$F$ $F_1$–$F_1$–$F_1$–$b_1$–$b_1$–$D$–$A_2$–$A$ $A_2$–$F_2$–$F$ $F_2$ to $G$. The two motors, the blow-out coil, and one-half the starting coil are in series, so that the second position is a notch, but is no more a running notch than the first, although it is a little more economical to run on, because the speed of the car is a little greater, which means that the counter E. M. F. of the armatures has taken the place of that part of the coil that has been cut out, and, as has been stated before, counter E. M. F. holds the current down without causing any heat losses.

**24.** On the *third position*, the $a_3$ drum tip makes contact with the $R_3$ finger and cuts out that part of the starting coil

that lies between the $r_2$ and $r_3$ posts. The path of the current is $W$–$S$–$T_1$–$a_1$–$a_3$–$R_3$–$r_3$–$r_4$–$A_1$–$A$ $A_1$–$F$ $F_1$–$F_1$–$F_1$–$b_1$–$b_1$–$D$–$A_2$–$A$ $A_2$–$F_2$–$F$ $F_2$ to the ground at $G$. The blow-out coil, one-quarter of the starting coil, and the two motors are all in series; so the third position is the third notch, but is not a running notch, in the true sense of the word.

**25.** On the *fourth position*, the drum tip $a_4$ comes in contact with finger $R_4$ and cuts out that part of the starting coil that lies between posts $r_3$ and $r_4$; also, drum tip $a_{4\frac{1}{2}}$ makes contact with finger $T$ and cuts out the solenoid $S$. Tip $a_4$ comes into action a little before the $a_{4\frac{1}{2}}$ tip does, so that before the $a_{4\frac{1}{2}}$ tip makes contact, the following condition obtains: All of the starting coil is cut out, but the blow-out coil is still in circuit and the path of the current is $W$–$S$–$T_1$–$a_1$–$a_4$–$R_4$–$r_4$–$A_1$–$A$ $A_1$–$F$ $F_1$–$F_1$–$F_1$–$b_1$–$b_1$–$D$–$A_2$–$A$ $A_2$–$F_2$–$F$ $F_2$–$G$. As soon as $a_{4\frac{1}{2}}$ touches finger $T$, the solenoid is cut out and the path of the current becomes $W$–$T$–$a_{4\frac{1}{2}}$–$a_4$–$R_4$–$r_4$–$A_1$–$A$ $A_1$–$F$ $F_1$–$F_1$–$F_1$–$b_1$–$b_1$–$D$–$A_2$–$A$ $A_2$–$F_2$–$F$ $F_2$–$G$. The notch in the star wheel of the controller index is so placed that the power drum notches when finger $T$ rests on the middle of tip $a_{4\frac{1}{2}}$ and finger $R_4$ rests on the middle of tip $a_4$. The fourth position, then, is not only a notch, but it is a running notch. It is the series-running notch; the two motors are in series across the line and all resistance is cut out. In passing from the fourth position to the fifth position, the $T$ finger leaves the $a_{4\frac{1}{2}}$ tip before the $R_4$ finger leaves the $a_4$ tip, so that the combination just after leaving the $a_{4\frac{1}{2}}$ tip is the same as it was just before the $a_{4\frac{1}{2}}$ tip went into action; that is, all the starting coil is cut out, but the solenoid is not. These two positions are the ones referred to above as not being numbered. The solenoid is cut in just in time to look after the arc that takes place on the $a_4$ tip in going from the fourth position to the fifth position.

**26.** On the *fifth position*, the $a_5$ tip makes contact with the $R_5$ finger, and as the $a_4$ tip has left the $R_4$ finger, that part of the starting coil which lies between $r_2$ and $r_4$ is cut

into circuit again, and the path of the current becomes $W$–$S$–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$–$A_1$–$A\,A_1$–$F\,F_1$–$F_1$–$F_1$–$b_1$–$b_1$–$D$–$A_2$–$A\,A_2$–$F_2$–$F\,F_2$ to the ground at $G$. The blow-out coil, one-half of the starting coil, and the two motors are in series, the same as they were on the second notch; the half of the starting coil is cut in again, to make the shock less in going into multiple. The fifth position is not a notch, and it is not marked, for it is not intended to be dwelt on; it is what is called a *transition* position.

**27.** The *sixth position* is also a position of transition. The $b_6$ tip comes into action on this position, and the lower $b_1$ tip goes out of action. The path of the current becomes $W$–$S$–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$–$A_1$–$A\,A_1$–$F\,F_1$–$F_1$–$F_1$–$b_1$–$b_6$–$G$. The No. 2 motor is dropped entirely out of the circuit, and the blow coil, one-half of the starting coil, and the No. 1 motor are in series. The sixth position is not a notch, and is not marked on the controller top.

**28.** On the *seventh position*, the two $c_7$ drum tips come in contact with the lower $D$ and the lower $R_4$ finger. The path of the current is $W$–$S$–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$ to point $o$, where the current splits into two parts; one part takes the path $o$–$A_1$–$A\,A_1$–$F\,F_1$–$F_1$–$F_1$–$b_1$–$b_6$ to the ground through finger $G$. The other part takes the path $o$–$R_4$ (the bottom finger of the power drum)–$c_7$–$c_7$–$D$–$D$–$A_2$–$A\,A_2$–$F_2$–$F\,F_2$ to the ground at $G$. The two motors are in multiple and are in series with the blow-out coil and one-half of the starting coil. The seventh position is a notch, and it is marked on the controller top, but it is not a running notch.

**29.** On the *eighth position*, the $R_3$ finger makes contact with the $a_8$ tip and cuts out the part of the starting coil that is between the $r_2$ and $r_3$ posts; the path of the current is $W$–$S$–$T_1$–$a_1$–$a_8$–$R_3$–$r_3$–$r_4$–$o$, from which point, the two paths are the same as on the last position. The blow coil and one-fourth of the starting coil are in series with the two motors, which are still in multiple. The eighth position, then, is a

marked notch, but it is not a running notch. On the ninth notch, as on the fourth notch, two changes take place; the $R_4$ finger makes contact with the $a_9$ tip and cuts that part of the starting coil that lies between $r_3$ and $r_4$; also, finger $T$ touches the $a_{9\frac{1}{2}}$ tip and cuts out the blow-out coil, leaving the two motors in full multiple across the line.

**30.** The *ninth position* is a notch, and is what is called the *multiple-running notch.* The $R_4$ finger touches the $a_9$ tip a little before the $T$ finger touches the $a_{9\frac{1}{2}}$ tip, so there is a short period of time when the starting coil is all cut out, but the blow coil is still in action. The two tips are so made in order that the blow coil may be cut into action again before the circuit is broken on the $a_9$ tip when the power drum is thrown to the off-position. The notches and positions may now be compared.

**31. Notches and Positions.**—The type S controller has seven marked notches. The first four notches are the series-notches, and the last three notches are the multiple notches. The fourth notch is the series-running notch, and the last notch is the multiple-running notch. The type S has twelve positions, of which nine only are marked as shown in Fig. 17. The three unmarked positions are the ones used to cut the blow-out coil into and out of circuit on each side of the fourth position and on one side of the ninth. To compare the notches and the regular positions: The first position is the first notch, which is a marked notch, but is not a running notch; the second position is the second notch, which is also a marked notch, but not a running notch; the third position is the third notch—a marked notch, but not a running notch; the fourth position is a marked notch and is the series-running notch; the fifth and sixth positions are not marked on the controller top, because the motorman is not supposed to stop on them; they are both change or transition positions. The fifth position is the same as the second, and on the sixth position there is only one motor in action, so that if the power drum is allowed to

rest on either of these positions in going from series to parallel, the speed of the car will die down until the seventh position is reached, when the car will probably jump ahead. The seventh position is a marked notch, but not intended to run on, because one-half of the starting coil is still in circuit. The seventh position, the fifth marked notch on the controller, is the first notch in multiple. The eighth position is the sixth notch on the controller, but as one-quarter of the starting coil is in the circuit, the notch is not for running. The ninth and last position, the seventh and last notch, is a running notch, because all of the starting coil is cut out as well as the blow-out coil or solenoid.

In Fig. 17, it would appear that the starting coil is divided into three equal parts, but this is not so; it is divided into three parts, but the resistance included between posts $r_1$ and $r_2$ is equal to the sum of the resistances in the other two sections; so that one-half of the total resistance is cut out on the second notch, one-half of the remainder on the third notch, and the remaining quarter on the fourth notch. Also, the first notch multiple includes one-half the starting coil.

**32. Reverse Switch and Cut-Out Connections.**— Fig. 18 shows the connections of the motor cut-out and reverse switch; the emergency-brake tips are left out, but this feature will be taken up by itself. Connection blocks $F_1$ and $R_1$ are dotted in, to show that they are the connecting board, but take no part in the reverse switch or cut-out combinations. Blocks $R_2$ and $R_3$ are left out, because, on account of the position of the starting coil in the diagram, they are not needed, and their use would only complicate the connections, without adding any points of interest. The shaded part of the blocks represents the reverse fingers; the open part, the connecting posts. To trace the path of the current through the several notches on the combination switch, assume the power drum to rest on the first notch; when the reverse drum rests on the notch marked *ahead*, the car moves ahead on both motors, and the path of the current is $T$–$S$–$T_1$–$a_1$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$r_4$–top

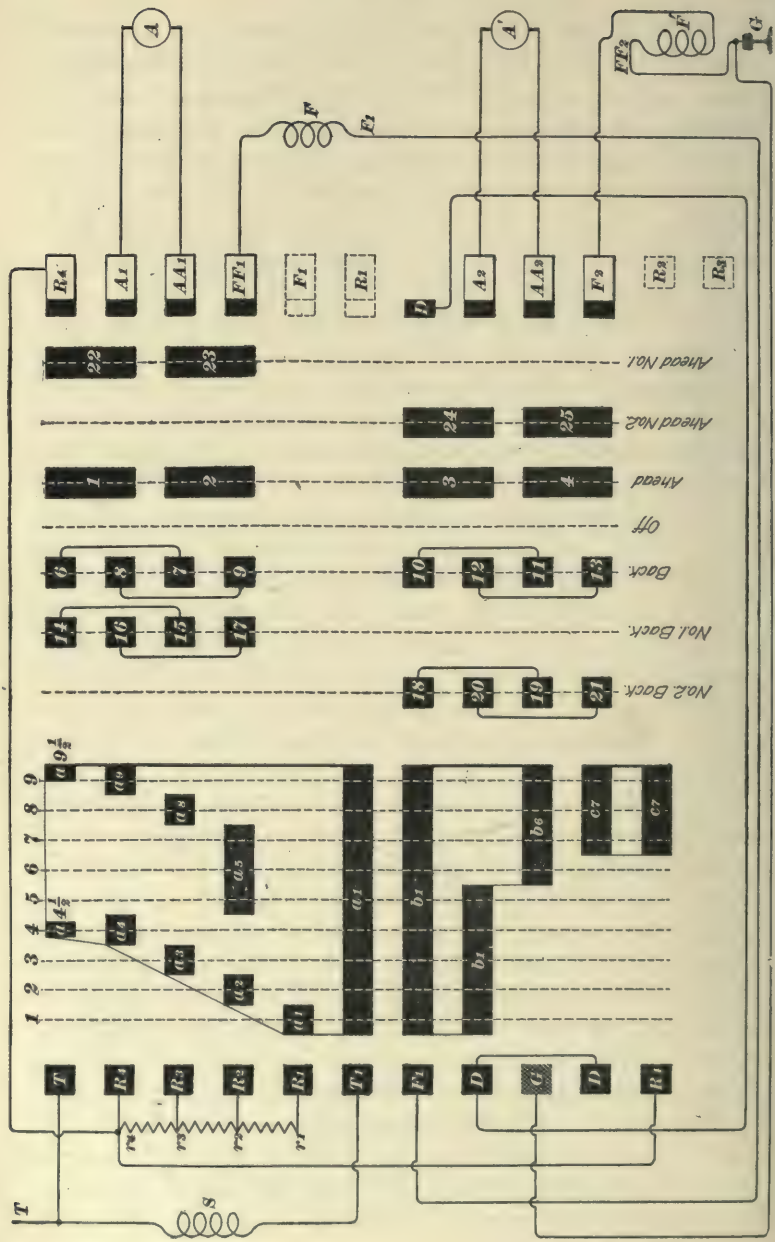

A
A'
F
G
FF2
F2
E1
R4
A1
AA1
FF1
F1
R1
D
A2
AA2
F2
R2
R3
Ahead No.1
Ahead No.2
Ahead
Off
Back
No.1 Back
No.2 Back
T
R4
R3
R2
R1
T1
F1
D
G
D
R1
S

FIG. 18.

reverse finger $R_4$–tip *1*–$A_1$–$A$ (the No. 1 motor armature)–$A$ $A_1$–tip *2*–$F$ $F_1$–$F$ (the No. 1 motor field)–$F_1$–$b_1$–$b_1$–$D$–$D$–tip *3*–$A_2$–$A'$ (the No. 2 motor armature)–$A$ $A_2$–tip *4*–$F_2$–$F'$ (the No. 2 motor field) and to the ground at $G$. It will be noted that the current goes into both armatures at their top ends; but it goes into the No. 1 motor field $F$ at the top end, and into the No. 2 motor field at the bottom end. The reasons for this have already been given a number of times.

When the reverse lever is put at the dotted position marked *off*, the circuit is opened all along the reverse drum and the power drum cannot be moved. When the reverse lever is on the position marked *back*, both motors reverse their direction of rotation and the car backs up. The path of the current is $T$–$S$–$T_1$–$a_1$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$r_4$–$R_4$ reverse finger–*6*–*7*–$A$ $A_1$–$A$–$A_1$–*8*–*9*–$F$ $F_1$–$F$–$F_1$–$b_1$–$b_1$–$D$–$D$–*10*–*11*–$A$ $A_2$–$A'$–$A_2$–*12*–*13*–$F_2$–$F'$ and to the ground at $G$. It must be noted that the current goes into and comes out of the two motor fields at the same ends that it did when the reverse lever was on the ahead position, but it now goes into the bottom ends of the two armatures and comes out of their top ends, whereas, on the ahead position, it went into the top ends and came out of the bottom ends.

By thus reversing the polarity of the armatures, the direction of rotation of both is reversed, and the car, of course, moves back instead of ahead. When the reverse lever is put on the notch marked *No. 1 back* the No. 2 motor is cut out, because the fingers to which it connects on the reverse switch hang in the air and cannot touch any of the tips, and the car moves back on the No. 1 motor, whose fingers still make contact with the tips *14*, *15*, *16*, and *17*; but when one motor is cut out, the car will not move until the power drum reaches the seventh position (the fifth notch), because the current cannot get across the gap made by cutting out one motor. As soon as the power drum reaches the first multiple notch, however, the motor that is cut in has an independent circuit of its own, and can move the car. When the power drum is on the first notch, and

the reverse lever is at *No. 1 back*, the current (or, rather, the pressure) can get as far as reverse finger *D* by way of path *T–S–$T_1$–$a_1$–$a_1$–$R_1$–$r_1$–$r_2$–$r_3$–$r_4$–$R_4$–14–15–A $A_1$–A–$A_1$–16–17–F $F_1$–F–$F_1$–$b_1$–$b_1$–D–D*, but can get no farther, because the finger *D* hangs in the air ; but if the power drum is turned to the fifth notch, the current finds its way through the No. 1 motor by way of path *T–S–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$* to the top reverse-drum finger *$R_4$–14–15–A $A_1$–A–$A_1$–16–17–F $F_1$–F–$F_1$–$b_1$–$b_6$* and to the ground by way of ground finger *G*.

The car backs up, because the reverse-drum connections are the same as they were for that motor on the back position. (The No. 1 motor will start on the sixth position of the power drum, when the No. 2 motor is cut out, because it is then that the $b_6$ tip touches the *G* finger and gives it a ground, but as the seventh position, the fifth notch, is marked on the controller top, while the sixth position is not, the fifth notch is referred to as the position on which the motor will start.)

The next position is *No. 2 back*. On this position, the No. 1 motor is cut out and the car cannot start on the No. 2 motor until the power drum reaches the fifth notch. If the power drum is on the first notch, the voltage can get no farther than the $R_4$ reverse finger, which hangs in the air ; but as soon as the power drum reaches the fifth notch, the current takes the path *T–S–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$* to the bottom power-drum finger *$R_4$–$c_7$–$c_7$–D–D–D–18–19–A $A_2$–A′–$A_2$–20–21–$F_2$–F′* and to the ground at *G*. On the *No. 1 ahead* position, the path of the current, when the power drum is on the fifth notch, is *T–S–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$–$R_4$* reverse finger–*22–$A_1$–A–A $A_1$–23–F $F_1$–F–$F_1$–$b_1$–$b_6$–G* to the ground at *G*. On the *No. 2 ahead* position, the path of the current, when the power drum is on the fifth notch, is *T–S–$T_1$–$a_1$–$a_5$–$R_2$–$r_2$–$r_3$–$r_4$* to the $R_4$ bottom power-drum finger–*$c_7$–$c_7$–D–D–D–24–$A_2$–A′–A $A_2$–25–$F_2$–F′* and to the ground at *G*. On the Walker type S controller, then, when one of the motors is cut out, the car must be operated on the last three notches. In throwing off, though, throw all the way off.

**33. Operation of the Emergency-Brake Position.**—Fig. 19 is a diagram of the connections used when the reverse lever is on the emergency-brake position. As has been stated elsewhere, a series-motor will not generate current, unless either its field or armature connections or its

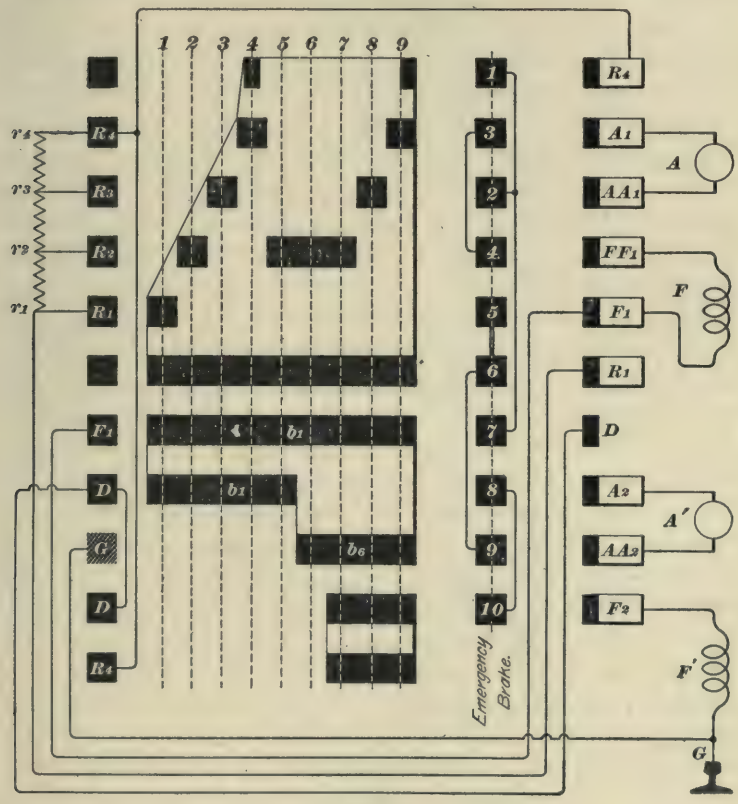



FIG. 19.

direction of rotation is reversed; that is to say, if the fields and armature of a street-car motor are connected up in a certain way, and the car, as a result of these connections, moves in a given direction, before the headway of the car can be used as the source of power to run one or both of the motors as a generator, either the field or armature must be

reversed. Any one of the three factors must be reversed, but not two of them. As an instance of how important it is to keep this point in mind, we will cite a case on record, where a very serious accident might have been avoided had the motorman known this. A great many motormen know that if a car is running ahead, it can be stopped, if the brakes fail and the fuse blows when it is tried to stop it with the reverse, by leaving the reverse handle on the reverse position and moving the power handle around to the multiple notch. In this case, the direction of rotation of the armatures is fixed by the motion of the car and, of course, cannot be reversed. The throwing over of the reverse lever reverses the connection of the field or the armature, according to the system in use, but not both, with the result that the two motors are thrown into a kind of loop circuit ; they are both connected up as generators and are opposed to each other ; the one that has the more residual magnetism starts to act first as a generator and runs its mate as a motor. As the resistance of the two motors is very low, and as they are the only resistance in circuit, the motor that is acting as a dynamo can send a very large current through itself and its mate. This brings to bear two influences that tend to stop the car. In the first place, as soon as the dynamo begins to generate, it puts a load on the car ; as there is no power to support this load, save what is due to the momentum of the car, the speed of the car must grow less, and it generally does so very suddenly. The other influence that tends to stop the car is due to the fact that if a street-car motor is connected up to run as a dynamo in a certain direction, it will run as a motor in the opposite direction. As soon as the reverse lever is thrown over, both motors become connected as dynamos to run in the direction dictated by the motion of the car. They both tend to act as dynamos, but both cannot actually act as dynamos because they are electrically opposed to each other, and one is stronger than the other. The result is that one of them must suffer itself to be run as a motor by the other. As soon as it begins to run as a motor, the direction of rotation of its armature is

reversed, and the car wheels geared to this armature slip around in the opposite direction to what the headway of the car itself is trying to send them. This, of course, has a retarding effect upon the speed of the car.

The accident referred to, in which three people were killed and eleven wounded, occurred as follows: A heavily loaded car was going up a steep grade about a mile long and the car was about half way up when the pole left the wire. The car started to go down the hill, and the motorman promptly put on his brake, but the brake would not work. The motorman knew that he had no power and could not use the reverse, because he heard the trolley pole rapping the span wires; he then called to the conductor to try the brake at his end of the car, but some of the platform passengers in their frantic efforts to get off the car had knocked the conductor into the street, so the motorman could not count on him, although he did not know it. The motorman stuck to his post and tried to stop the car by making the motors generate. He had practiced it many times just for such occasions as this, and he knew exactly how to do it, *just as he had done it before.* He pulled his hood switch, threw over the reverse lever and put the controller around to the first multiple notch; he even had presence of mind enough not to throw the controller handle too far around, for fear of stripping a pinion or burning off a motor wire. But all his presence of mind did no good.

The mistake was made in pulling the reverse lever over. If the car had been going ahead, this would have been the proper thing to do, but the car was backing; its direction of rotation had been reversed, and this alone changed the conditions so that the motors could have generated if the power handle had been just put on the multiple notch. By pulling over the reverse lever, two of the factors spoken of above became reversed; the motor fields (in this case) were reversed, and the direction of rotation of the armatures. *Only one of the factors need be reversed.* If a car is running ahead, the reverse switch must be pulled over and the power handle thrown over to a multiple notch. This rule applies, of course, going

down hill, if the car is being run from the controller on either end. If the car is being backed from either end and the brakes fail or the power goes off the line, it is necessary to throw the reverse lever over and to put the power handle around on multiple; but, if the car is going up a hill and the power fails and the brakes will not work, the reverse lever must be left where it is—it must *not* be thrown over. As long as the car runs from the power, its direction of motion is dictated by the position of the reverse lever. If the car keeps on running in that direction and it is desired to stop it by making the motors generate, the reverse lever *must* be thrown over before the power handle is moved to a multiple notch; but, if the car starts to move backwards, its direction of motion is no longer dictated by the position of the reverse lever, and, since by the very fact of the car moving backwards, the direction of rotation of the armatures is reversed, the reverse lever must *not* be touched.

**34.** When a motorman wishes to practice making the motors generate to stop the car, he must bear in mind that the hood switch must be opened before he starts; if it is not, as soon as the reverse lever is put on "back up" and the power drum is put on the first notch, the car will be stopped by the ordinary reversal of the motors. Of course, in time of trouble, when the brakes fail, a motorman will always try to stop his car with the reverse, before he attempts to make the motors generate. It is the trial of the reverse that reveals to him the fact that there is no power. There may be power on the line, but perhaps the fuse is blown, or some wire is burned off. Even if the fuse is burned out by the very act of trying to reverse the car, the motors can still be made to stop the car by generating, because the fuse is not in the loop or local circuit of which the two motors form a part, when they become dynamos.

Of course, in emergency stops, it is of no use to open the hood switch, for such a stop, with the motors as dynamos, is only supposed to be made when the brakes fail and there is no power with which to make an ordinary reversal. In

using such an electric brake, the motorman must not rely on it to bring the car to a full stop on a grade. It will bring the speed down to a value where the car just crawls along, but the car will not stop; so if it is going down a grade crossing and a train is coming, the best thing to do (after the electric brake has slowed the car down) in the absence of other means, is to block the car wheels.

These remarks will impress the student with the importance of using some judgment when trying to stop a car with the reverse lever. If the reverse switch is thrown over and the power handle is moved right around to the loop, the fuse is almost sure to go if the car is under good speed. The power handle should not be turned past the first notch until the motorman can feel the effect taking hold.

**35.** In Fig. 20 (*a*) and (*b*), $T$ is the trolley and $G$ is the ground. $A$ and $F$ are the armature and field of the No. 1 motor; $A_1$ and $F_1$ are the armature and field of the No. 2 motor. Fig. 20 (*a*) shows the path of the current when the ordinary reversal is made with the power by means of the

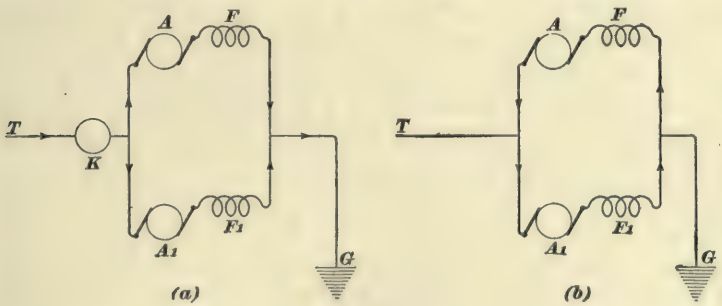



FIG. 20.

reverse switch. The current goes through the hood switches, one of which is shown at $K$, and also through the main-motor fuse, which is not shown; it then passes through the two motors to the ground as shown, when the power drum is over on a multiple notch. Fig. 20 (*b*) shows the loop or local circuit around through the two motors when they are made to generate. It is easy to see that the hood switches

and the main-motor fuse are not in the circuit at all. The arrowheads show the path of the local circuit.

**36. The Brake Circuit.**—The Walker emergency brake is, like all other electric brakes, actuated by current generated by the motors themselves. From the very nature of things, such a brake cannot bring a car to a stand on a down grade, because the motor that acts as a dynamo cannot generate any current unless its armature is in motion, so that, as soon as the car comes to a stand, the braking power of the motor ceases. On the Walker emergency brake, whose connections are shown in Fig. 19, the motors are not opposed to each other in a loop or local circuit, but they can be made to send a current through the starting coil. When the reverse lever is put on the emergency position, the No. 1 motor sends a current through the whole of the starting coil, by way of the loop or local circuit, top reverse finger $R_4$–*1–2–A* $A_1$–*A*–$A_1$–*3–4–F* $F_1$–*F*–$F_1$–*5–6–*$R_1$–$r_1$–$r_2$–$r_3$–$r_4$ and across to $R_4$ again. The No. 2 motor cannot generate yet, because one end of it is permanently grounded at *G* and the other end must get a ground before the circuit is complete. This it does on the sixth position, when power finger *G* touches tip $b_6$, and the No. 2 motor has a local circuit *G–F′–*$F_2$*–10–8–*$A_2$–*A′–A* $A_2$*–9–6–5–*$F_1$–$F_1$–$b_1$–$b_6$–*G*. The brake, of course, applies as soon as the reverse lever is put on the emergency position, because the local circuit of the No. 1 motor is entirely independent of the power drum; but the power drum can be used to increase the power of the brake, because, when the drum is moved around, some of the resistance of the starting coil is cut out and the braking current becomes larger. At times, it may be necessary to cut out some of the starting coil, for a series dynamo will not support a current through a given resistance when its speed gets below a certain value; so it may happen that the first application of the brake, together with the car's natural tendency to slow down, may bring the speed down below this critical value.

**37. Points of Interest.**—It must be noticed that the armature connections are reversed on the brake position just

as they are on the back position shown in Fig. 18. The current enters at the lower end of the armatures instead of the top ends, as it does when the car runs ahead. This is the single change that must be made in order to convert the motors into dynamos. This brake, like all electric brakes that depend for action on the current generated by the motors, can be made to stop the car only when it runs one way. In order that the lever might be applicable to both directions of rotation, there would have to be another brake position. The brake, then, could not be relied on in case the car commenced to roll backwards down hill, because the motors would not be connected up as generators for that direction of rotation and there would be no notch to throw the lever to, in order to so connect them. In such a case, the reverse lever would be allowed to rest on the ahead position, shown in Fig. 18, when the motors would brake themselves the same as they do on a controller that has no emergency-brake position.

To revert to the accident mentioned in a preceding article, due to the throwing of the reverse lever when it should not have been thrown, it will be instructive to state that the same law that governs the use of the reverse lever in making an ordinary reversal governs it also when using it to connect the motors up as dynamos. If the car is running ahead, as in ordinary service, and it is necessary to make an ordinary reversal to stop it, the power handle is thrown off, the reverse handle is thrown to the back position, and the power handle is thrown on again. The throwing of the reverse handle allows the current to go into the reverse end of fields or armatures, as the case may be, changes their polarity, and makes the armatures reverse their direction of rotation. On a controller whose reverse lever has no emergency-brake position, to stop the car under similar conditions, the same thing is done; but, in this case, the line power may be cut off from the controller entirely by the throwing of the hood switch, because the dynamo circuit is a local one, as shown in Fig. 20. The throwing of the reverse lever reverses the fields or armatures the same as it did before, but, in this case, it simply connects the motors so that they can generate.

To stop a car by an ordinary reversal when the car is running back, the power drum is thrown off, the reverse lever thrown ahead, and the power drum thrown on again. To stop the car under the same conditions, by making the motors generate, the same steps are gone through. There is one great point of difference, not in manner, but in degree, and it is an *important* one. When stopping a car by an ordinary reversal, the power handle, when it is put on again after throwing the reverse switch, must not be advanced beyond the first notch until it can be felt that the speed has been checked somewhat by the line current that flows on this notch, because, when a car is reversed under headway, the counter E. M. F. of the motors adds itself to the line voltage, and can send more current through the starting coil than the line voltage alone could. If the resistance in the starting coil is cut down by moving the power handle to the third or fourth notch in a jump, the current becomes so large that the main-motor fuse is blown, or the car wheels are made to slip around with no traction at all, leaving the car more helpless than ever. Of course, "if she fails to take hold" on the first notch, it means that there is probably an open circuit on that notch, and the power handle must be advanced to the next notch, and so on. If the reverse fails to work on any of the series-notches, advance the power handle cautiously to the first multiple notch, where the two motors have an independent path, and where, if there happens to be an open circuit in one of the motors, the other motor can take hold. If the reverse fails to work on any of the notches, the power is off the line, the main-motor fuse is gone, or there is an open circuit in the main-motor circuit, in any of which cases, bear in mind, that the reverse switch is *already* thrown, and if the power drum is left on the multiple notch a few seconds, the motors will become generators and stop the car themselves.

The trouble is that, under the great excitement of the moment, when the motorman finds that his reverse will not work and he tries to use the motors as brakes, he is likely, almost involuntarily, to throw off the power drum and throw

the reverse switch ahead again, under which condition the motors cannot, of course, generate when the car is running ahead. When it is desired to make a stop, using the motors as dynamos, the power handle must be shoved right on around to the multiple side of the controller, because the motors will not generate when the power drum is in any other position.

**38.** In all the cases just cited, the car has been supposed to be moving in the direction indicated by the reverse lever at the time the occasion of stopping arose. Now, when, as in the case of the accident referred to in a preceding article, the car is going up the hill and the loss of power and failure of the brakes allow it to roll down the hill, the following conditions exist: When the car was going up the hill, the reverse lever was, of course, in the ahead position; after the car commenced to roll down the hill, the reverse lever was still in the ahead position, where it ought to be and where it ought to stay. In the case of the accident, if the reverse handle had been left in the ahead position, then, every time the pole, in its gyrations on top of the car, happened to hit the wire, the car's speed would have been checked. When the car is going up the hill and it is desired to have it back down the hill quickly, in time of trouble, throw the reverse lever to back position; but in order to have it go up the hill or stop it, when it is rolling down, the reverse lever should be on the ahead position.

What has been said in regard to position of the reverse lever for making an ordinary reversal under these conditions, holds good for braking the car with the motors. When the car is running in the direction that the reverse lever points, the reverse lever must be thrown over to stop it; but when the car is running in the opposite direction to that toward which the lever points (if the car is wired properly), the lever must not be moved.

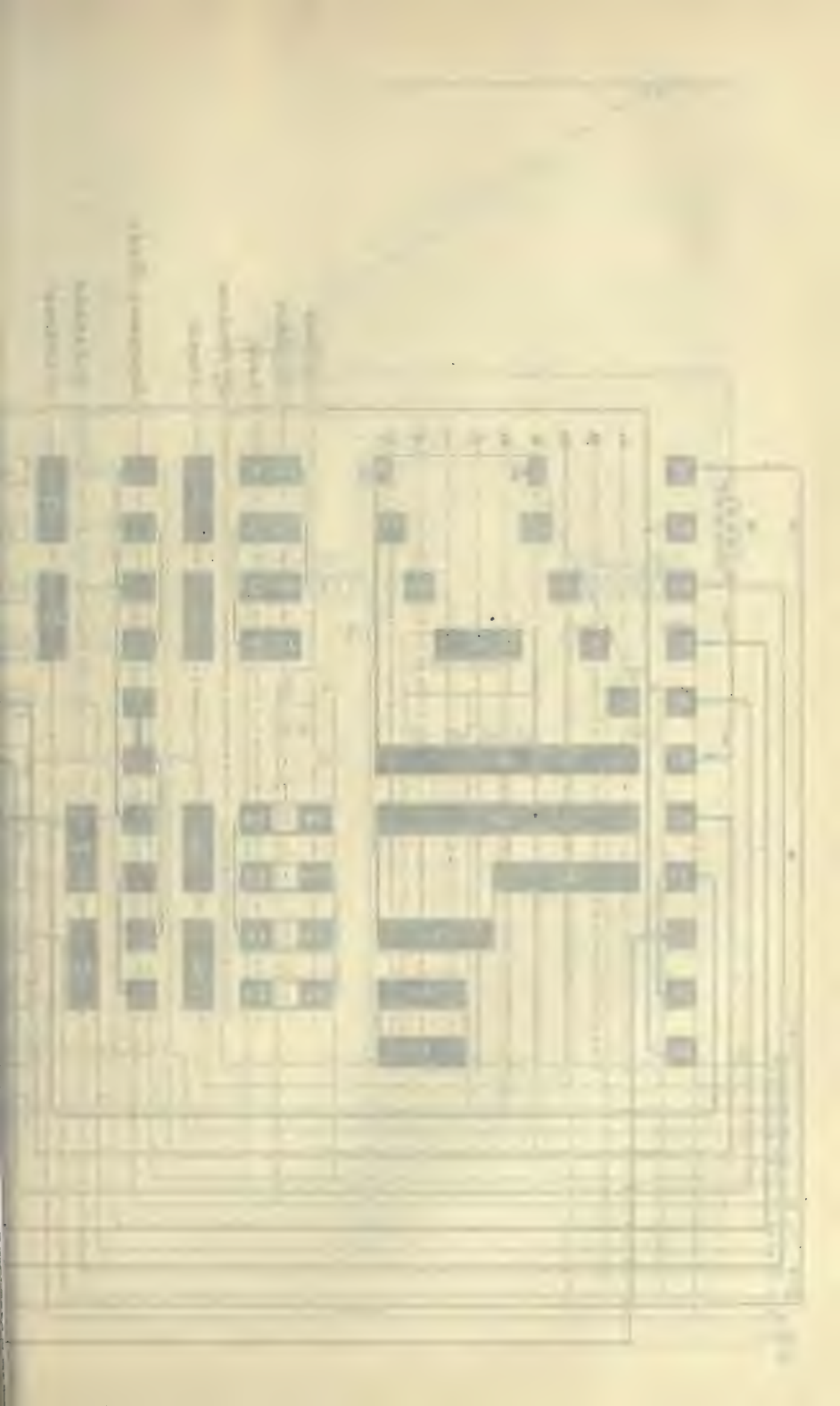
**39. Grounds.**—Fig. 21 is a general car-wiring diagram for one type S Walker controller and two motors of any kind. To connect in a controller on the other end of the

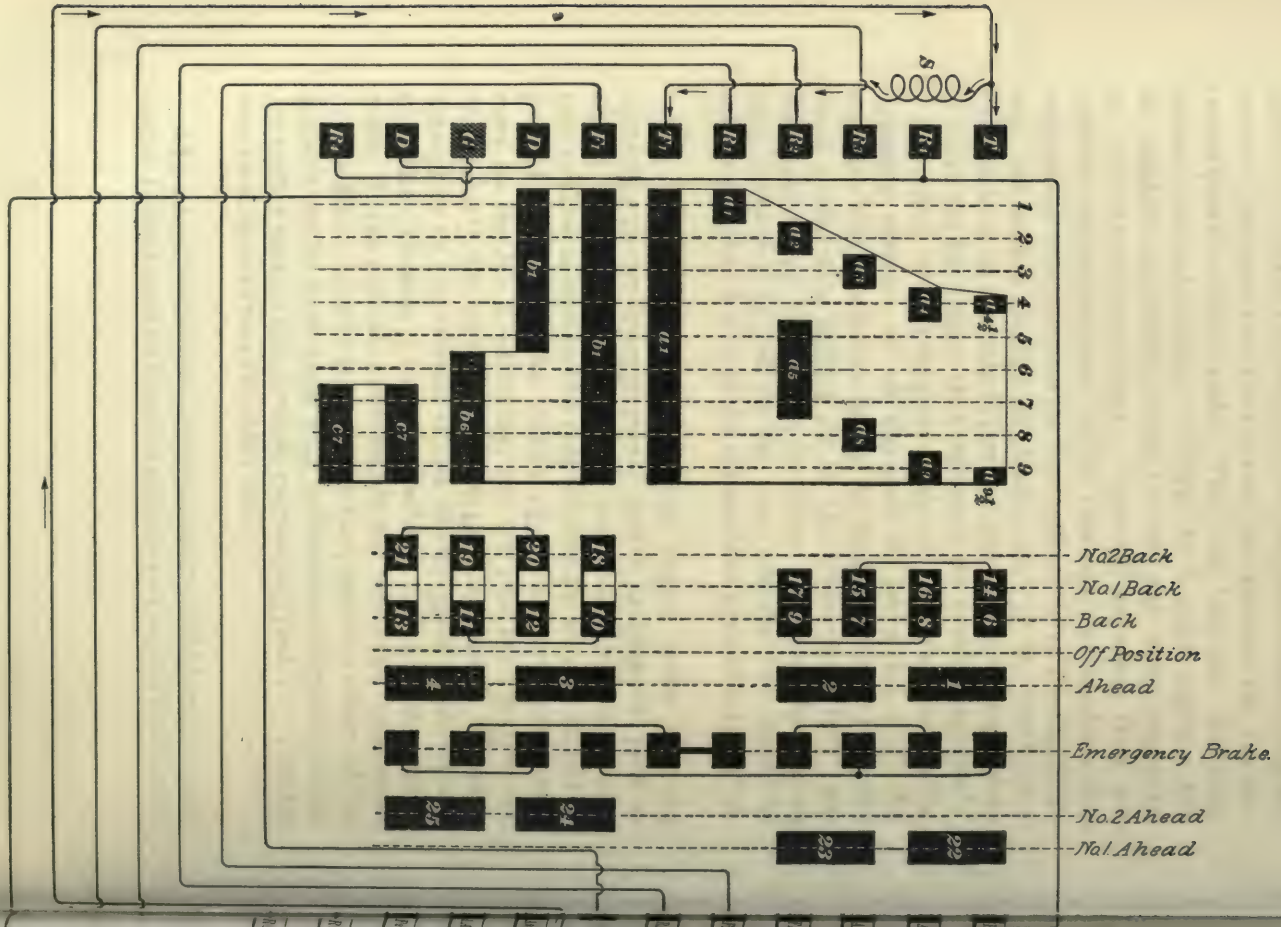
car, the lettered ends on the right-hand side of the drawing are run to the other controller just as they are marked, except that either the field or the armature wires must be reversed, in order that the car may run the way the reverse switch points on both ends. The fuse box and lightning arrester are not shown, as it will be a good exercise for the student to connect them in the way they ought to go. *W* is the trolley wheel. A ground anywhere from the wheel to the positive side of the fuse box will not blow the main-motor fuse, because the fuse will not be in the short circuit; but such a ground will burn a part of the trunk wire loose as soon as the pole is put on, and it will be impossible to move the car from either end until the break is repaired.

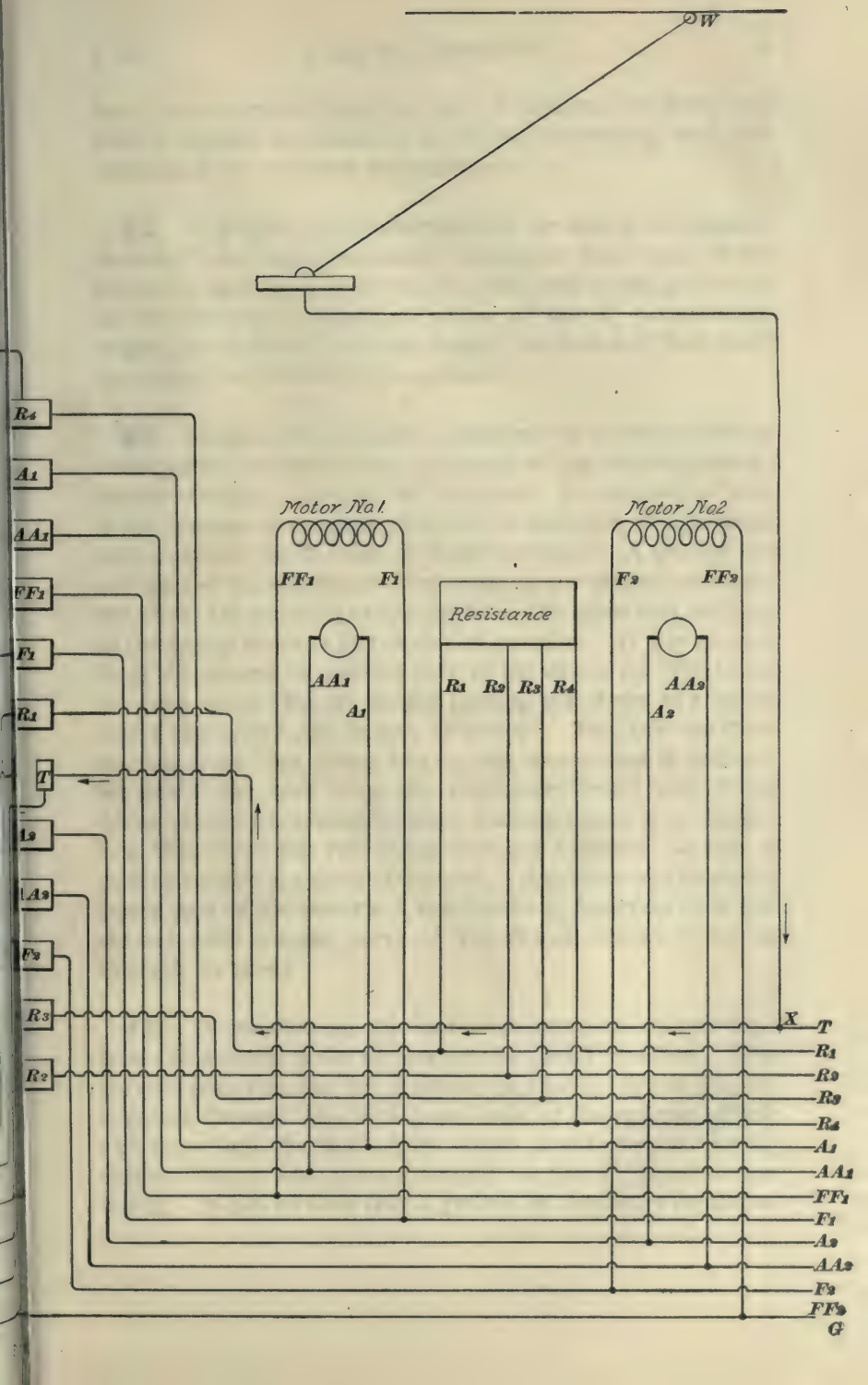
A ground on the negative side of the fuse box, on the lightning arrester, or on any part of the wiring from the negative side of the fuse box to the point *X*, where the main trunk trolley wire splices on to the trolley wire that runs from one end of the car to the other, will blow the fuse as soon as the pole is put on the wire, and the car cannot be run from either end until the cause of the ground is removed.

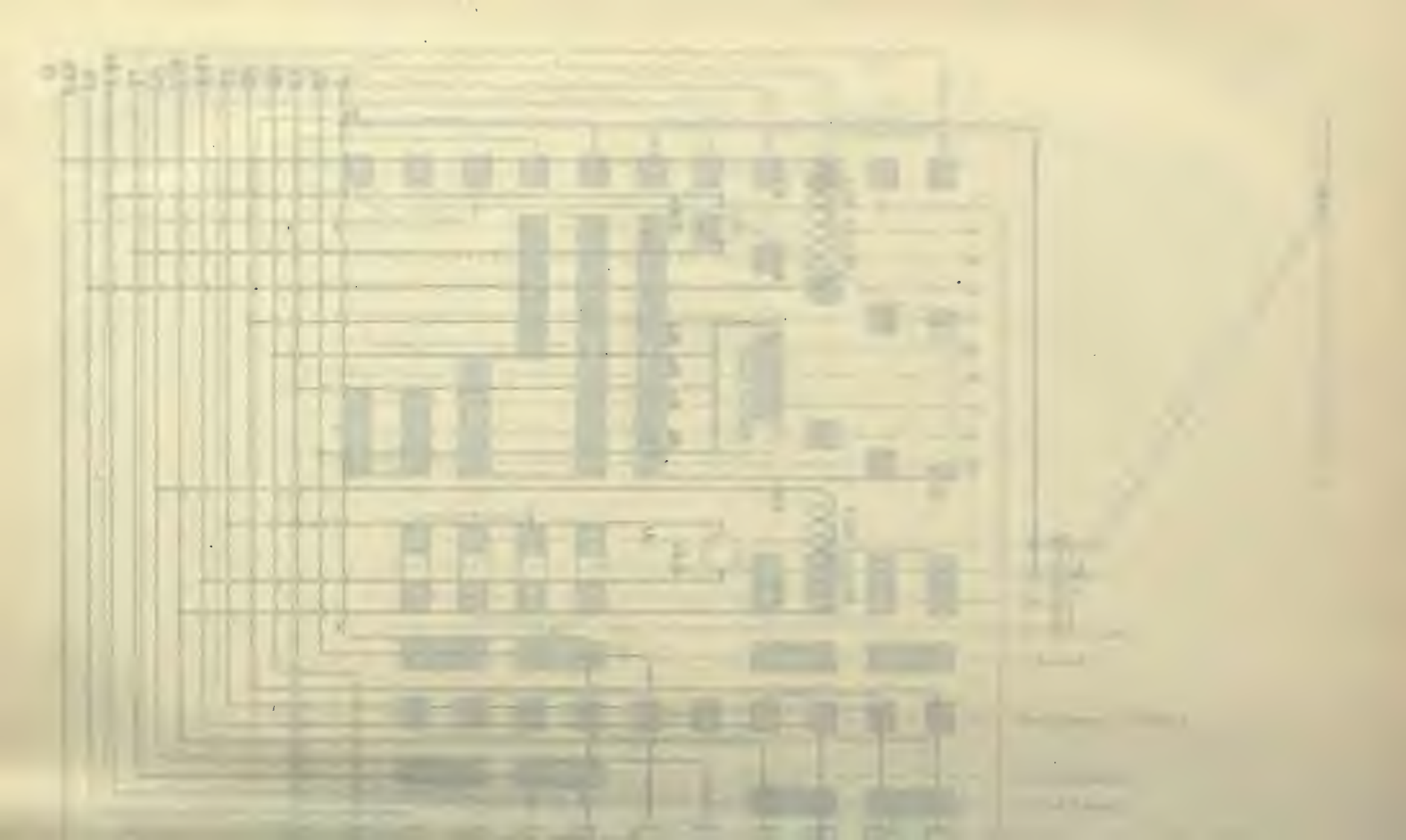
**40.** A ground anywhere from trolley splice *X* to the controller power-drum fingers *T* and $T_1$ (follow the path as shown by the arrowheads) will also cause the main-motor fuse to blow as soon as the pole touches the wire; but, as this ground would be on the branch of the car trolley wire that runs to the No. 1 controller, the car can be run from the No. 2 end if this wire is cut at the point marked *X*. Grounds take place on this stretch of the circuit quite often on any controller, because it includes the blow coil and its connections. If the ground occurs within the controller itself, more or less fireworks will indicate the fact, and the effect of the ground can be done away with by disconnecting the controller trolley wire at the reverse connecting post *T*. The car can then be run from the other end.

**41.** A ground on the *A* drum casting will blow the main-motor fuse as soon as the controller is put on the first notch,




No2Back
No1Back
Back
Off Position
Ahead
Emergency Brake.
No2Ahead
No1Ahead


W
Motor No1
Motor No2
Resistance
FF1
F1
AA1
A1
R1
R2
R3
R4
F2
FF2
AA2
A2
T
X
G



but if the controller is left at the off-position, its drum can have a ground anywhere on it without interfering with the running of the car from the other end.

**42.** A ground on the starting coil or any of its connections will blow the main-motor fuse on the first notch, if the ground is anywhere near the $R_1$ post; but if the ground is on or near the $R_4$ post, on either of the $R_4$ power-drum fingers, or on the $R_4$ reverse finger, the fuse will hold until the second or third notch is reached.

**43.** None of the grounds considered up to and including these points can be cut out by means of the cut-out switch, because being in the part of the circuit in common to both of the motors, even when they are in multiple, the grounds are outside of the domain of these switches. A ground on any part of the combination reverse cut-out brake drum cannot affect the running of the car from the other end, as long as the faulty drum is left at the off-position. If the ground is on the reverse or cut-out part of the drum, its effect can be done away with by simply turning the drum to a notch where the faulty part is out of action. The car can then be run from that same end on the motor that is still cut in; but if the fault is on the emergency-brake part of the drum, this notch cannot be used, because there is a connection that joins the two motor circuits together, so that a ground on one is a ground on both. A ground on the emergency part of the drum will not, however, interfere with the cut-out and reverse parts of the drum, unless it burns through to them.

**44.** In considering the motors themselves, we will suppose the reverse drum to rest on the ahead position. The current goes into the No. 1 motor on the $A_1$ reverse finger; it passes through the armature back to the reverse switch and goes into the field, from which it returns on the $F_1$ reverse finger and passes around to the $F_1$ power-drum finger. It can be seen that a ground on the No. 1 armature

can be gotten rid of by turning the reverse lever to a point where the No. 1 motor is cut out. It must be borne in mind that when one of the motors is cut out, the other motor must be operated on the three last notches of the controller; so that although the $F_1$, $F_1$ internal controller wire is grounded when the No. 1 field is grounded, and it also touches the $b_1$, $b_1$ drum casting on the first notch and grounds it, it cannot affect the circuit of the No. 2 motor, because the No. 2 can get no current until the fifth notch, when the $D$ finger has passed off the $b_1$ casting. The cut-out switch, then, can cut out a ground on any part of the No. 1 motor, and the No. 1 motor circuit extends from reverse finger $A_1$ to power-drum finger $F_1$.

**45.** A ground on the $D\,D$ internal controller wire cannot be cut out by means of the switch; it is the wire that carries the current from the No. 1 motor to the No. 2 motor when they are in series. Suppose the reverse drum is on the *No. 1 ahead* position. The current takes the path $T$–$S$–$T_1$–$a_1$–$a_1$–$R_1$ through the starting coil back to top reverse finger $R_4$–$22$–$A_1$–$A\,A_1$–$23$–$F\,F_1$–$F_1$–$F_1$ and right through the $b_1$, $b_1$ casting to the $D$ finger, to which the grounded wire runs. The No. 1 motor should not start until the fifth notch (to be more accurate, the sixth position), when it gets its ground through $b_6$ and finger $G$; but if wire $D\,D$ is grounded, the No. 1 motor will start on the first notch, even when the No. 2 motor is cut out. Next suppose the reverse lever to rest on the *No. 2 ahead* position; the path of the current, then, on the fifth notch is $T$–$S$–$T_1$–$a_1$–$a_5$–$R_2$–$R_4$–$R_4$–$c_7$–$c_7$–$D$ and through the fault on wire $D\,D$ without getting to the No. 2 motor at all; there will be a big flash in the controller, when the drum is thrown to the off-position, because there are only two breaks in the circuit—at fingers $D$ and $R_4$.

**46.** A ground anywhere on the No. 2 motor is controlled by the cut-out switch and, of course, has no effect when the switch is turned to a point where the No. 2 reverse fingers

hang in the air. If, therefore, there shows up a ground that blows the main-motor fuse before the power drum is moved at all, the ground is somewhere between the negative side of the fuse box and the trolley fingers on one of the controllers. If an inspection proves this fault to be between the fuse box and the splice $X$, it must be gotten rid of before the car can be moved from either end. If it is between $X$ and the connecting post $T$, it must either be removed or the car wire cut between $X$ and $T$ before the car can be moved from either end. If the ground is in the controller itself, between connecting post $T$ and power-drum finger $T$ and $T_1$, its influence on the other end of the car can be removed by taking the trolley wire out of the $T$ connecting post. If the main-motor fuse blows as soon as either controller is put on the first notch, the probabilities are that there is a ground on the circuit somewhere between $R_1$ and $R_4$, and it must be removed before the car can be run from either end, because the starting coil and all of its wires are in common to both controllers.

**47.** A ground anywhere on the circuit from $W$ to $R_4$ cannot be cut out by means of the cut-out switch. If it happens to be on the power drum, however, it cannot affect the No. 2 controller as long as the faulty drum is left at the off-position.

**48.** A ground on either motor can be cut out by means of the cut-out switch; but a ground on the $D\,D$ wire cannot be, and it will disable the car at both ends, unless the $D\,D$ wire is disconnected at both ends, because this wire leads into the reverse drum when the No. 2 motor is cut in, and it grounds the No. 1 motor on the first notch when that motor is cut in and the fault is transmitted to the other end of the car through the $F_1$ wire, which is common to both.

**49.** When, on account of a ground, a motor is cut out on one end of the car, the car cannot be run from the other end until the motor is cut out on that end too, for all the

motor wires are common to both controllers. If the car bucks when the fault takes place, it may be certain that the fault is on a field or armature or on some of their connections; but if the car does not buck, it does not necessarily mean that the ground is not on one of these devices. In any event, try to cut it out on the faulty end; if it cannot be cut out on the faulty end, the chances are that it cannot be cut out on the other end either, but before trying to cut it out on the good end, disconnect the trolley wire on the faulty end.

# CAR EQUIPMENT.

(PART 10.)

## THE JOHNSON COMPANY'S SYSTEM.

### THE JOHNSON MOTORS.

**1.** The Johnson Company have been manufacturers of motors for only a few years. They succeeded the Steel Motor Company, who were the pioneers in using steel for the frames and shells of street-car motors. The Steel Motor Company did quite a business on small roads with the old type C motor, but as the demand for faster and stronger motors became greater, it was decided to change the type of the motor to one more in line with the demand created by the motors made by the General Electric and Westinghouse Companies. The result was a round, four-pole motor, similar to the prevailing types in some respects, but radically different in others. A short time previous to the coming out of this improved motor, the Steel Motor Company went into the hands of the Johnson Company, who now furnish motors ranging in size from 25 to 150 horsepower. As the 30 and 50 horsepower motors are the ones best adapted to ordinary street-railway work, they alone will be considered.

### THE NO. 20 MOTOR.

**2.** The No. 20 motor, Fig. 1, is rated at 30-horsepower input and is made for use on narrow-gauge roads, 1 meter



For notice of the copyright, see page immediately following the title page.

(39.37 inches) or wider, and for service where light cars and easy grades do not call for a stronger machine. There are many of these motors in use outside of large cities.

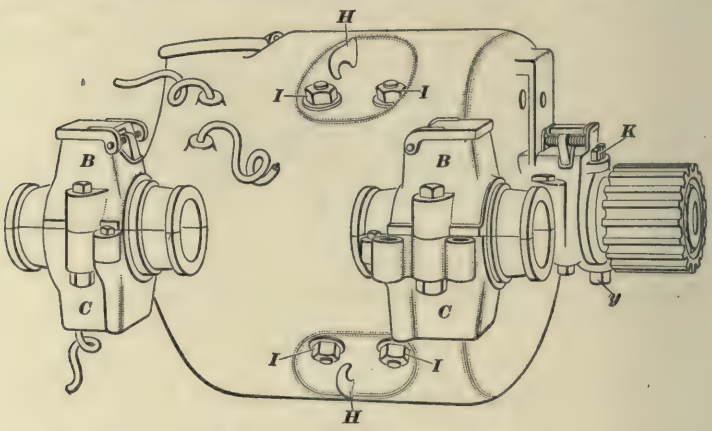



FIG. 1.

**3. The Frame.**—The frame is made of low-carbon steel and cast in two halves loosely hinged together by means of links *L*, *L*, Fig. 2. The figure shows the motor with the lower case dropped, in which position either the armature or the top fields may be removed without disturbing any other part. The pole pieces, four in number, are laminated, but the boss, or seat, on which they fit, is cast with the motor shell and is then machined to fit the base of the pole piece. The axle-bearing brackets *B*, *B*, Figs. 1 and 2, hang over and rest upon the top of the axle; these and, also, the armature-bearing caps are cast in one piece with the top motor shell. The axle caps *C*, *C*, Figs. 1 and 2, bolt on from beneath, and each one has an oil well. Dowel-pins guide the two halves of the motor together, so that bolt holes *b*, *b*, *b*, *b*, Fig. 2, can be cored and stock bolts used.

Only two sizes of bolts are used on the motor, so that a double-end socket wrench will do any wrench work that may be necessary. Some motors require six or seven sizes of bolts; this not only increases the storeroom account, but, also, the time and cost of a repair job or inspection. Taking

out four bolts *b*, *b*, *b*, *b*, Fig. 2, allows the lower shell to be swung down, with or without the armature, as the case may require; without the armature, if the nut is removed from the bottom of the two yokes *y*, *y*, Figs. 1 and 2, and with the armature if these two nuts are left on the bottom end of the yokes, and the split keys, one of which is shown at *K*, Fig. 1, are drawn from the slot in the tops. The lower half is so swung on its links, that when swung down with care, there is no danger of the armature rolling out of its seat in

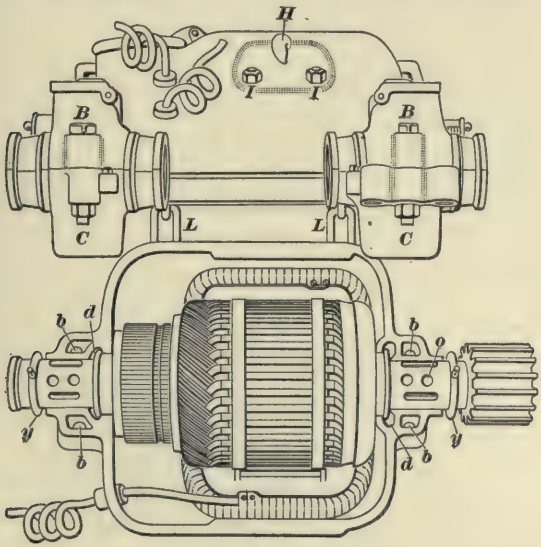



FIG. 2.

the lower shell. As the lower half, once down, swings *from* the axle, it is easy to get at it from the end of the car. By unhooking the links, the lower half can be removed entirely with or without the armature. The frame is provided with ring ways in which run the oil guards on the armature shaft, so that all excess of oil and grease is thrown into the street instead of into the motor. These oil or ring ways are shown at *d*, *d*, Fig. 2. Holes *o* are to receive, from the armature caps, dowel-pins that prevent the sleeves from turning with the shaft. The pole pieces are of laminated wrought iron,

and so constructed that on the horns, only every other plate comes to the surface; this practice is adopted on most modern motors, and, as shown before, serves to reduce heating and sparking. The pole pieces are bolted down on seats machined at the same time as the armature caps. The bolts *I*, *I*, Figs. 1 and 2, have their heads let in flush with the surface of the pole piece, and pass outside of the frame where they are secured with nuts and lock-washers. There is nothing special about the bolts. Hooks *H*, *H* are for handling the motor.

**4. The No. 20 Armature.**—The No. 20 armature, Fig. 3, is of the well known series-connected drum type, but it has several unique features, among which are the connection of its leads, the dimensions of its bearings, and the method of mounting the commutator on the shaft. These points will be taken up later. The core is well ventilated and is built up of plates of soft Swedish iron well japanned, to stop local currents in the core. The plates are secured between steel

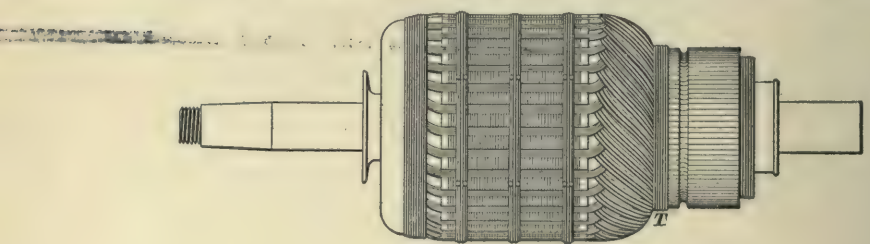



FIG. 3.

heads that have a long bearing on the shaft. The head on the commutator end extends out along the front end of the shaft in the form of a sleeve that is tapered and key-seated to take the tapered commutator; this manner of construction largely does away with loose commutators and the evil that follows such a fault—open-circuited armatures—because as soon as a commutator gets loose, it is apt to break the coil leads. The core is hollowed out, thereby not only giving a good path for the circulation of the air and improving the radiation, but, also, cutting down the weight

of the armature and its tendency to spark at the higher loads. The core has but 33 slots, so that each tooth is strong and well able to resist injury. The commutator has 99 bars, so that the armature must have 99 coils, or 3 coils per slot. Three coils are done up together, well insulated, provided with a kind of insulating armor outside and pressed into shape in a steam press. The coil is placed in the press and partly screwed down; the steam is then turned on and the coil softens; as it softens, the press is screwed down more, and the operation kept up until a series of stops, which regulate the dimensions of the coil, prevent any further screwing down. The steam is then turned off and cold water allowed to circulate through the press; this hardens the coil so that it can be removed and handled without any fear of injury to its shape. When the coil comes out of the press, its surface is as smooth as glass; the whole mass is hard and firm, and the armature core requires no insulation in the slots.

The commutator is of the undercut bar type. In Fig. 4, (*a*) shows an undercut bar, and (*b*) a bar that is not undercut. An ear is formed by turning a groove in the commutator; the ears are milled to receive the armature-coil leads, whose ends are tinned, as are the slots in the ears, and tightly driven into the slot and then swaged to secure good electrical contact. Both the slots and the ends of the leads are tinned to prevent corrosion, but the leads are not soldered in, as they are on other modern makes of armatures. This was a very bold departure from the time-tried custom, and everybody said it would not work, but, strange to say, it does work and saves considerable labor and material. After being driven home in the slots, the leads are held down with a heavy twine band, shown at *T*, Fig. 3. Another ingenious

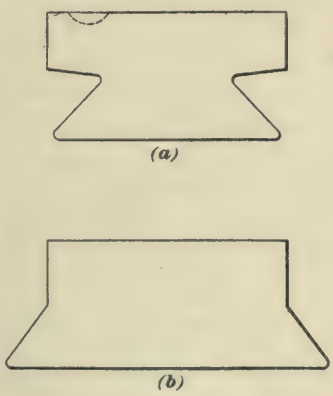


FIG. 4.

feature to be found on this motor is the insulation of the commutator shell from the shaft of the armature. The commutator is forced on to the steel sleeve over a layer of tough insulating paper, with the result that the shell is not a ground and there is very little tendency for the current to jump from the commutator bars to the shell. When the commutator is forced on, it is tested from shell to shaft with a 500-volt lamp circuit; if the lamps fail to light, the job is a good one, and is passed; but, if the lamps do light, the commutator is pressed off, reinsulated, and pressed on again. The insulation of the commutator is mica; the bars are hard-drawn copper. Each of the coils, before being grouped for pressing, contains five turns of No. 9 B. & S. gauge, double cotton-covered copper wire, so that a pressed coil (containing three individual coils) has in it fifteen turns of No. 9 wire, and six leads coming from it. Since each slot contains one side of two coils, each slot has thirty wires in it.

**5. The No. 20 Field Coil.**—Fig. 5 shows the general appearance of the No. 20 field coil, which contains 129 turns of No. 4 B. & S. wire; it is of the mummified type (a mixture of chalk and japan being applied to it in the course of its winding, after which it is put in an oven and baked), is firm and hard and can be dropped on the floor with little liability to injury. All four fields are exactly alike and are, therefore, interchangeable; but in putting in a new set of fields, or in replacing a faulty one, the usual precautions must be observed in placing the field and in connecting it. Assuming that the fields have been put in correctly in the first place, it is an easy matter to replace one field and connect it the same as the one that was taken out; but, inasmuch as it is a very easy matter to get a coil turned end for end, which would reverse its polarity, weaken the whole motor field,

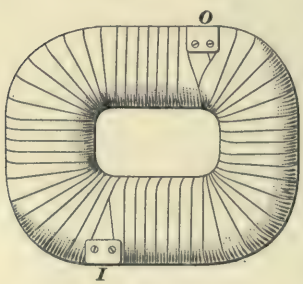


FIG. 5.

make the brushes spark badly, increase the current, and roast not only itself but the three other field coils, the two lugs are marked so that there will be no excuse for a mistake. One lug is marked *I*, which means that the inside end of the winding is connected to that lug. The other lug is marked *O*, and means that the outside end of the winding is connected to that lug. In replacing a coil, simply bear in mind that it must be put in so that two lugs having the same mark shall go together. The No. 20 coils are held securely in place by plates of spring steel, against which the flanges of the pole pieces press when the pole pieces are drawn home. The pole piece draws on the plate and the plate draws on the field. This idea is a good one; in the first place, the spring-steel plate takes up any shrinkage that might and does take place in the insulation of the field after several months of service; in the second place, the steel plate exposes a large surface to the field coil, so that the pressure brought to bear in drawing the coil firmly home is spread over a large area and there is much less danger of cutting into the insulation than when the field is held by the pole flange itself.

**6. The No. 20 Brush Holder.**—Fig. 6 shows the outline of the No. 20 brush holder. The holder is mounted on a wooden block that is bolted to a lug cast on each side of the top motor shell. The adjustment to allow for wear in the commutator is made by sliding the holder radially on a machined brass casting that tips the end of the wooden arm and serves as a guide. The brush holder, being radial and rigid, once set right, calls for no other adjustment. The proper tension is secured by means of a spiral spring and lever that provides a fairly uniform pressure throughout the life of the brush. There are two brushes in each holder and the holders are staggered so that no ridge is worn in the center of the commutator. The

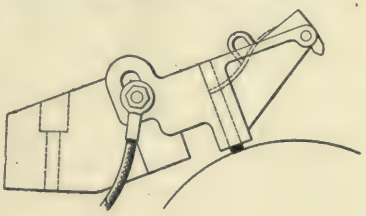


FIG. 6.

brush terminal wires are connected to the brush holder itself; and are brought out of the motor shell, one on each side, through soft rubber bushings.

**7. The No. 20 Bearings.**—The axle bearings are Babbitt-lined, cast-iron sleeves 12 inches long. They can be filled and bored to any diameter from $3\frac{1}{2}$ inches to $4\frac{1}{2}$ inches, and are interchangeable. On top are grease pockets from which the grease reaches the axle through two slots 30° apart. Besides these, the caps beneath are provided with oil chambers, to be packed with woolen waste and filled with oil. Suction draws the oil through the waste to the axle. The armature bearings are, also, Babbitt-lined, cast-iron sleeves and have the most liberal dimensions of any motor of the size on the market. They are alike on both ends and are, therefore, interchangeable. The armature bearing on the commutator end runs 3 inches up into the commutator shell and is surrounded by an oil guard; the bearing on the pinion end extends into the shield and also has an oil guard. The outer ends of the bearings project outside of the motor frame and serve as a means for slinging the armature when removing or replacing it. The inner ends also take the yoke, already referred to, provided for retaining the armature in the top shell or letting it down with the bottom, when the motor is opened. The end play of the armature is controlled at the pinion end. The armature being light, the life of its bearings is long. The No. 20 motor weighs about 1,200 pounds.

**8. The No. 20 Gearing.**—The No. 20 gear is made of cast steel and has 65 teeth. The pinion is drop forged, taper bored, and has 16 teeth. This makes a gear ratio of 65 to 16 $= \frac{65}{16} = 4.06$.

---

### THE NO. 34 MOTOR.

**9.** This motor, Fig. 7, is rated at 50 horsepower, but, being of liberal dimensions both in its electrical and

mechanical details, the No. 34 motor could well stand being rated at 60 horsepower and still have a margin of safety.

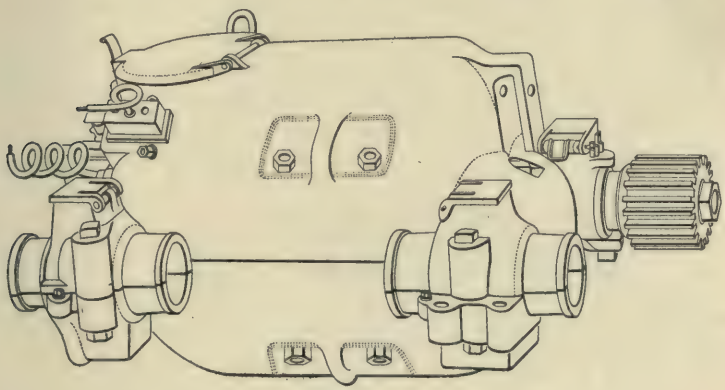


FIG. 7.

**10. The Frame.**—The frame of the No. 34 motor is of the same general outline as that of the No. 20 motor. It is of low-carbon cast steel, made in two halves, semiround in form. In each of the halves, or shells, are cast two seats, or bosses, that are bored to receive the pole pieces. The axle-bearing brackets hang over and rest on the top of the axle, as shown at *B*, *B*, Fig. 8. These brackets, together with the armature-bearing caps and suspension lugs, are cast with the top shell of the motor. The two shells are clamped together and the pole seats and armature-bearing seats bored at the same time so that perfect alinement is assured. Dowel-pins guide the two halves of the motor together so that cored holes and rough bolts can be used to hold them. All of the main bolts are standard stock bolts that are kept in any storeroom for ordinary repairs, and only two sizes of bolts are used on the motor. The removal of four bolts allows the lower half of the motor to swing down by links and eyebolts supported from lugs on the upper half, just as in the case of the No. 20 motor. By unhooking the link, the lower half can be taken off entirely, and, according as the split key in the top or the nut on the bottom of the double-shanked eyebolt, shown at *I*, *I*, Fig. 8,

is removed, the armature is kept in the bottom or the top shell.

In Fig. 8, the split key has been drawn from the top of the double-shanked eyebolt, so that the armature remains in the lower shell. The frame is provided with the usual oil ways, so that all excess of oil and grease is thrown into the street by the oil guards on the armature shaft, and does

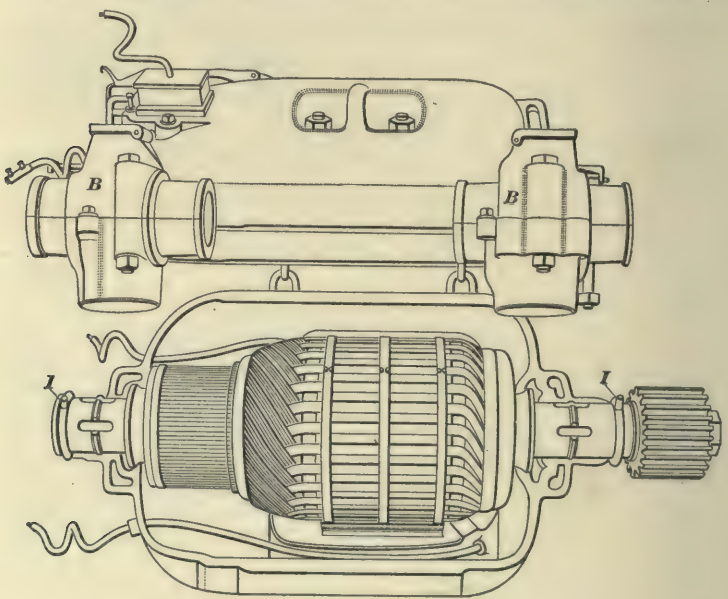



FIG. 8.

not get into the motor. Access to the inside of the motor to inspect or replace brushes, is gained through a door in the top shell of the motor, just over the commutator. As on the motor, the pole pieces are separate devices and are secured to their seats by bolts whose heads are let into the face of the pole piece and whose shanks pass through the frame to the outside, where they are drawn home with a nut and secured with a lock-washer. There are two bolts to each pole piece. The pole pieces are built up of plates of soft iron, adjacent plates being turned end for end.

**11. The No. 34 Armature.**—The No. 34 armature is similar to the No. 20, but is, of course, larger on account of the increased capacity. The first thing that strikes the critical observer is the size of the commutator; it is built up of mica and hard-drawn copper, and is unusually long. The coils are bound in groups of three and pressed into shape in a steam press, as previously described. Fig. 9 shows a No. 34 armature. The core has 33 slots, and the

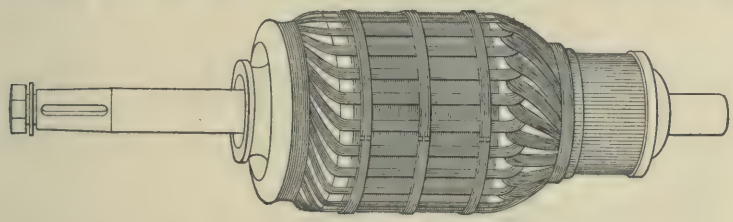


FIG. 9.

commutator 99 bars. It takes, therefore, 33 complete coils, or 99 single coils, to wind the armature. Each single coil is made up of three turns of No. 7 B. & S. copper wire, and each complete coil contains, therefore, nine turns of wire; since each slot contains one side of two complete coils, each slot contains 18 wires, and the whole core, 33 slots, has $33 \times 18$ wires $= 594$ active wires. The commutator fits on a tapered seat and is insulated from this seat by a layer of insulating paper.

**12. The No. 34 Field Coil.**—The No. 34 motor has four field coils, which are all alike and that are, therefore, interchangeable. Instead of being wound on a form, as in the case of the No. 20 field coil, the No. 34 field coil is wound on a shell of its own; this field shell has two guides on the back, and these guides are machined to gauge, to receive the two flanges of the pole piece, which flanges press against the guides and draw the field shell into place, when the pole-piece bolts are screwed home. The field coil, in the course of its winding, is freely swabbed with a mixture of chalk and japan, and after being baked in an oven, is as hard as a brick.

Fig. 10 is a cut of the No. 34 field coil. $T, T$ are the connecting lugs; $G, G$ are the guides against which the pole-piece flanges bear; and $R$ is a pocket cast in the rear face of the shell to make room for the copper lead connecting to the inside end of the winding. If one has any idea at all as to the theory of connecting field coils, he cannot get a set of No. 34 fields connected incorrectly. On the No. 34 coil, there is absolutely no excuse for getting the two ends confused. The inside end must come out at the raised place $R$, because there is no room for it to come out anywhere else. The simple rule to bear in mind when replacing a No. 34 field is the old rule that holds good on any street-car motor; i. e., *connect like ends together.* It is possible to get a No. 34 field turned end for end; but in such a case, in order to get like ends together, it would be necessary to run the connecting wire all around one of the coils, and the clumsiness of such a job should at once show that something was wrong. The field cannot be put in top side down, because its shape and the brass shield will not permit it. The No. 34 field coil is wound with two No. 5 B. & S. wires in multiple. There are 172 turns of No. 5 wire on the coil, but only 86 effective turns, because the field is wound two wires in multiple. To state the facts a little differently, the cross-section of a No. 5 wire is 33,102 circular mils (a mil is $\frac{1}{1000}$ of an inch and a circular mil is the area of a circle whose diameter is 1 mil), so that the area of two No. 5 wires in multiple is 66,204 circular mils, which is very little less than the exact area of a No. 2 B. & S. wire. If the coil were wound with a No. 2 B. & S. wire, only about 86 turns could be put on. A coil wound with a No. 2 B. & S. wire would work just as well as one wound with two No. 5 wires, but the two No. 5 wires are used because it makes a more flexible and easily wound conductor.

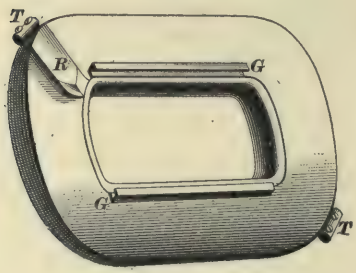



Fig. 10.

**13. The No. 34 Brush Holder.**—The No. 34 brush holder is the same as the No. 20, except that it is larger.

**14. The No. 34 Bearings.**—The axle bearings are cast-iron shells lined with babbitt; they are 12 inches long and can be bored to $4\frac{1}{2}$ inches. The grease cups are on top and the grease feeds to the axle through two slots. The armature bearings are also Babbitt-lined, cast-iron sleeves; they are the same on both ends and the side play is controlled on the pinion end.

**15. The No. 34 Gearing.**—The No. 34 axle gear is of cast steel and the pinion is of hammered steel. The teeth on both are cut from solid hammered-steel blanks and are uniform throughout. The pinion is taper bored to fit the tapered seat on the armature shaft. Both are enclosed in a malleable iron gear case, in the top of which is a hole through which to feed the gear grease. The gear has 69 teeth and the pinion has 16 teeth, making a gear reduction of 4.31.

---

## THE JOHNSON CONTROLLERS.

**16.** Owing to litigation over patents principally relating to the use of the magnetic blow-out, the Johnson controllers have not come into very extended use and the total number in operation is small, compared with those made by the General Electric and Westinghouse Companies. We will, however, call attention here to a few points regarding them without going into details as fully as was done with the previous types. By this time, the student should be able to trace out the various combinations for himself, when given a diagram of the wiring.

---

### THE TYPE 34 CONTROLLER.

**17. General Description.**—Fig. 11 shows the Johnson Company's No. 34 controller. This controller has several novel features. Among these are the finger board, the

disposal of the blow-out coil, the combination cut-out and reverse switch, the locking device, and the doing away with a connecting board altogether. In Fig. 11, *C* is the blow-out coil, which is made up of about 60 turns of No. 3 B. & S. wire, the coil being treated to a mixture of chalk and japan to make it hard and strong; on the bottom, the coil sets in a wooden block cut out to fit the curved end of the coil; the block itself is set into an iron pocket in the controller bottom. On top, the coil is held by two L bolts whose shanks pass through the controller back, where, by means of two nuts, the coil is drawn back snugly against a wooden block placed between the coil and the iron controller back. The iron power drum acts as a core for the blow coil and the lines of force across the arcs are so well directed that no arc guards are used, except when the motors to be controlled are large and the starting-coil resistance, therefore, low.

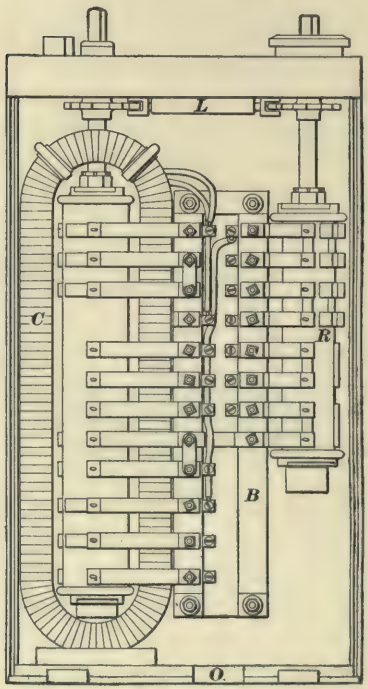


FIG. 11.

The locking device is very simple. It has already been shown in *Car Equipment*, Part 7, and consists of two plungers working in opposite ends of a cast-iron sleeve supported from the controller back; the plungers slide back and forth in the sleeve, and in doing so alternately compress and release a common spiral spring that lies between the two plungers in the sleeve and gives the springy "feel" to the power-drum handle as it is turned from notch to notch; by taking out or putting back an iron washer, a place for which is

made in the iron sleeve, the controller can be converted from an interlocking to a non-interlocking controller without in any way impairing the "feel" of the power notches. This was done to avoid litigation, when suits for infringement of patents were so common. *B* is the finger board; it is nothing but a wooden trough running down between the two drums. Under every finger is a brass or copper casting, one end of which serves as a washer to insure good contact with the finger, and the other end, as a connector to take the wires from the car hose. It will be noticed that there is no regular connecting board. The wires from the car hose run straight up to the fingers themselves and such a thing as a grounded controller wire is unheard of. Every wireman will appreciate the scheme for getting the hose wires into the controller. The cable hole *O* is cut through to the front edge of the controller apron, so that to set up a controller, it is a very easy matter to bend the wires back out of the way. *R* is the combination reverse drum and motor cut-out. The cutting out of a motor is done with the reverse handle.

**18. The No. 34 Power Drum.**—Fig. 12 shows the No. 34 power drum; it has in it four separate castings so disposed that those that connect together are placed next to each other, in this way doing away with all strips and wires on the drum. There are three features about this drum not found on any of the drums previously shown. In the first place, the casting $a_1$, $a_2$, $a_3$, $a_4$ is not used to make or change any combinations of connections; it is used simply to put two more breaks in the circuit, so that the tips and fingers are not so badly taxed when the drum is thrown on and off, or when it is thrown from series to parallel, or vice versa; the more places in which an arc is broken, the less burning goes on in each place. The next unique feature is that to throw the drum on or off, it must be turned in the opposite way, in respect to the fingers, to what we are used to in turning drums. To put the No. 34 drum on, the handle must be turned in the direction of the hands of a clock, the same as on any other controller, but it must be noticed that in doing so,

the drum tips move from the fingers; in throwing the drum off, the tips move toward the fingers. On all other controllers, the reverse is true. The reason is this: on most controllers the power and reverse finger boards are, as a rule, on the outer edge of the drum in both cases. On the No. 34 power drum the single finger board being in the center, the two sets of fingers must stick out on either side, and hence are in the opposite direction to what we are used to seeing them. Stress is laid on this point, because, from the fact that the finger board is on this side of the drum, the drawing of the same is apt to appear peculiar, and the student is liable to get confused in tracing out the path of the current unless he bears the point in mind. In Fig. 12, the first position is on the opposite side of the drum from what we are used to seeing it, because the finger board is on that side. This same drum would do to use with a finger board placed on the left-hand side. The point of support of the fingers has simply been changed over, the buttons on the fingers remaining in the same place.

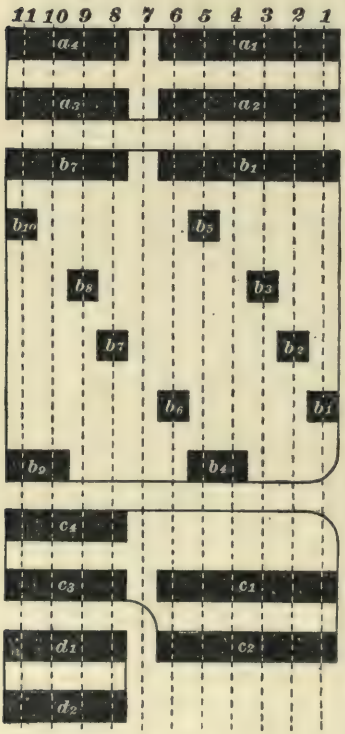



FIG. 12.

The next point to notice is that none of the drum contact rings $a_4$, $b_7$, $c_3$, etc. run all the way across the drum. After leaving the sixth position no tip on the drum makes contact with a finger until the eighth position is reached. In other words, this is a drum of the "open-circuit" type. In going from series to parallel, both motors are dropped by opening the circuit; after which they are again picked up

in multiple, instead of in series, and have a resistance in ahead of them. If one of the hood switches on the car be opened, the power drum advanced to the seventh position, and the hood switch put in again, the car will not start, because of the open circuit; but if the drum be moved either way, the car will start with the motors either in series or in multiple, according as the handle is turned farther on, or toward the off position.

**19. The No. 34 Combination Reverse Switch and Motor Cut-Out.**—Fig. 13 is a diagram of the No. 34 reverse switch and motor cut-out; by means of it, the direction of motion of the car can be reversed or either motor can be cut out without opening the door of the controller; it is all done by means of the reverse lever. The reverse lever occupies the usual place on the right-hand side of the controller top, and, by the direction of its inclination, shows in which direction the car should start; there is not anything unusual in the appearance of the reverse drum, except that there are more tips on it than would be needed to simply reverse the motors. An ordinary reverse drum has two rows of tips on it corresponding to a go-ahead and a back-up position of the lever. The No. 34 reverse drum has on it six rows of tips corresponding to the six active positions indicated in Fig. 14, which is a reproduction of the marks to be found on the No. 34 top in the line of travel of the reverse lever. Counting the off position, there are seven positions

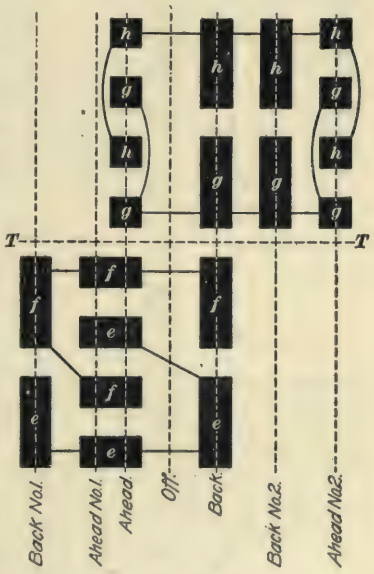



FIG. 13.

to which the reverse lever can be turned; the off position is the only position in which the lever can be removed from the drum shaft; running around the path of travel of the lever is a sort of L guard, not shown in Fig. 14. The nose of the lever lifts against this guard when an attempt is made to take the lever off, except at the off position, where a slot that lets the nose of the lever through is cut in the guard. The two positions marked simply *Back* and *Ahead* in Figs. 13 and 14 are the two positions to be found on every reverse switch or drum, and when the reverse lever is on either of them, both motors are in circuit. If the lever is moved over to where the nose points at *Ahead No. 1*, the No. 2 motor is cut out and the car runs ahead on the No. 1 motor. In Fig. 13, all of the drum tips above the dotted line *T T* belong to the circuit of the No. 2 motor and all of the tips below that line are in the circuit of the No. 1 motor; so it can be readily seen that the reason the No. 2 motor is cut out when the lever is on the *Ahead No. 1* notch is that the fingers belonging to the No. 2 motor do not touch any of the drum tips; these fingers hang in the air just to the left of the four tips marked *h*, *g*, *h*, *g*; if the lever nose points at *Back No. 1*, the No. 2 motor is still cut out and the car backs on the No. 1 motor. On the *Back No. 2* notch, the No. 1 motor is cut out and the car backs on the No. 2; on the *Ahead No. 2* notch the No. 1 motor is still cut out and the car runs ahead on the No. 2. In Fig. 13, it will be noticed that all tips bearing the same letter are shown connected together; on the drum, this is done by means of overhanging castings—no connecting strips are used.

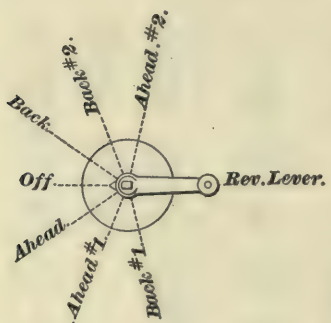


FIG. 14.

**20. The No. 34 Internal Connections.**—Fig. 15 shows the No. 34 internal connections, of which there are only four;

power-drum fingers *1* and *2* are connected together with a strip of copper and so are power-drum fingers $R_4$ and $R_4$. There are only two cross-connections in the whole controller; one is a flat strip of copper running from power-drum finger $R_4$ across to reverse-drum finger $R_4$; the other connection is a piece of No. 4 B. & S. stranded cable running from power-drum finger No. *3* to reverse-drum finger No. *3*. As both of them run their entire length in the bottom of the wooden trough, they cannot ground.

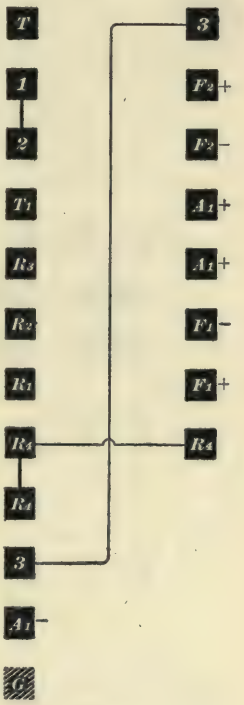


FIG. 15.

**21.** Fig. 16 is a complete car-wiring diagram for one No. 34 controller and two motors. To put in another No. 34 controller, the marked ends on the right-hand side of the drawing are run to the second controller and connected to the fingers that have the same name; bearing in mind, of course, that in order to have the car run the way the reverse lever points on that end, either both field wires or both armature wires must be reversed in the No. 2 controller. On the No. 34 controller, it is more convenient to reverse the two field wires, because in the controller they connect to adjacent fingers. In Fig. 16, the path of the current, as shown by the arrowheads, is on the first notch ahead *W–K–K–FB–LA–P–S–T–*$a_1$*–*$a_2$*–1–2–*$b_1$*–*$b_1$*–*$R_1$*–*$r_1$*–*$r_4$*–*$R_4$*–*$R_4$*–*$R_4$*–*$e_1$*–*$e_3$*–*$e_4$*–*$F_1$*−−*$F_1$*+–*$F_1$*−−*$F_1$*+–*$f_4$*–*$f_3$*–*$f_1$*–*$A_1$*+–*$A_1$*+–*$A_1$*−−*$A_1$*–*$c_2$*–*$c_1$*–3–3–*$h_1$*–*$h_6$*–*$F_2$*−−*$F_2$*−−*$F_2$*+–*$F_2$*+–*$g_6$*–*$g_1$*–*$A_2$*+–*$A_2$*+–*$A_2$*−−*G*. The $A_2$− brush lead is bolted directly to the frame of the No. 2 motor.

It will not be necessary to trace the path on the other steps. This is left as an exercise for the student. The various combinations are, however, indicated in Fig. 17, where *T* is the

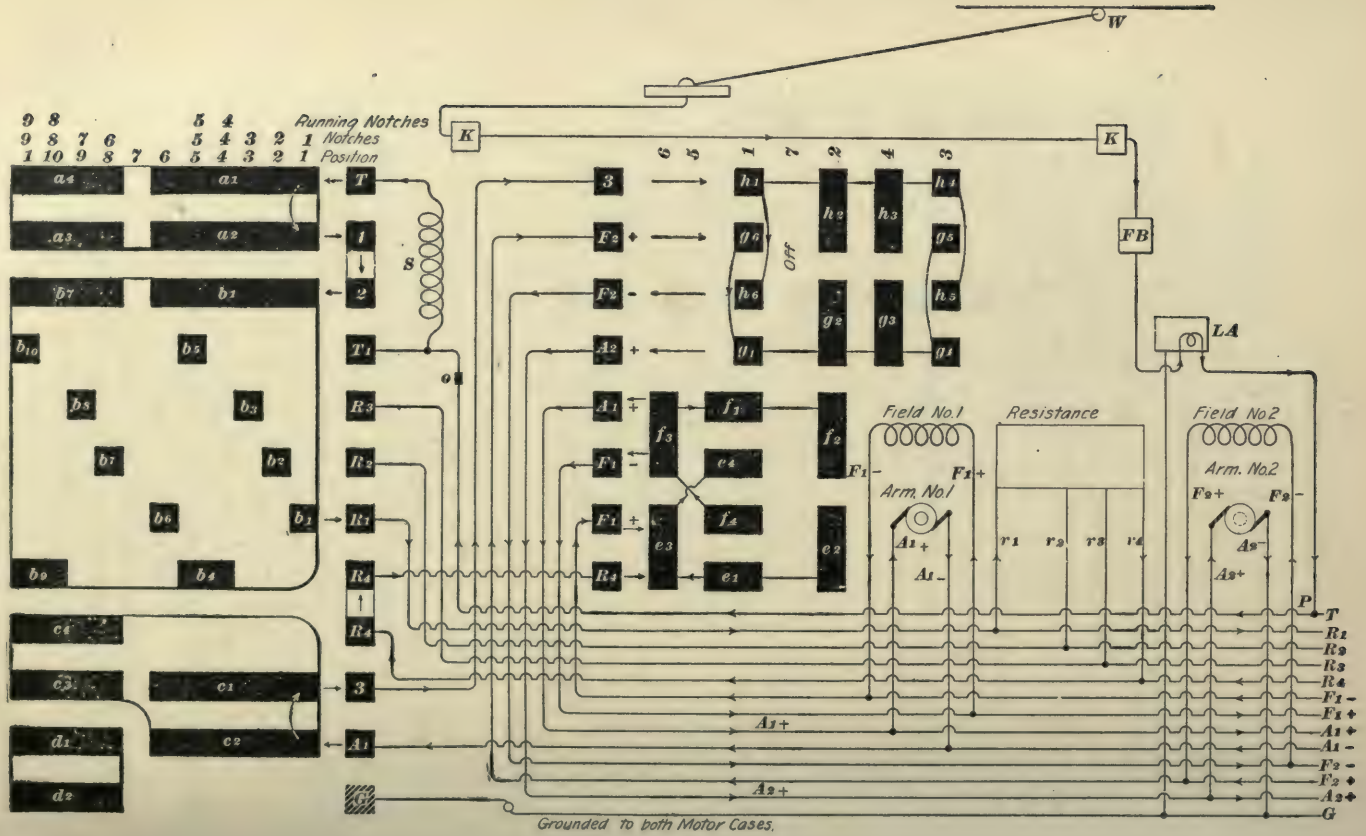

W
K
K
FB
LA
Running Notches
Notches
Position
Off
Field No.1
Resistance
Field No.2
Arm. No.1
Arm. No.2
S
Grounded to both Motor Cases.
T
R1
R2
R3
R4
F1 −
F1 +
A1 +
A1 −
F2 −
F2 +
A2 +
G
P

FIG. 16.

trolley, $M$ the blow-out coil, *1*, *2*, *3*, *4* the resistance points, and $F_1$, $A_1$, $F_2$, $A_2$ the fields and armatures of the motors.

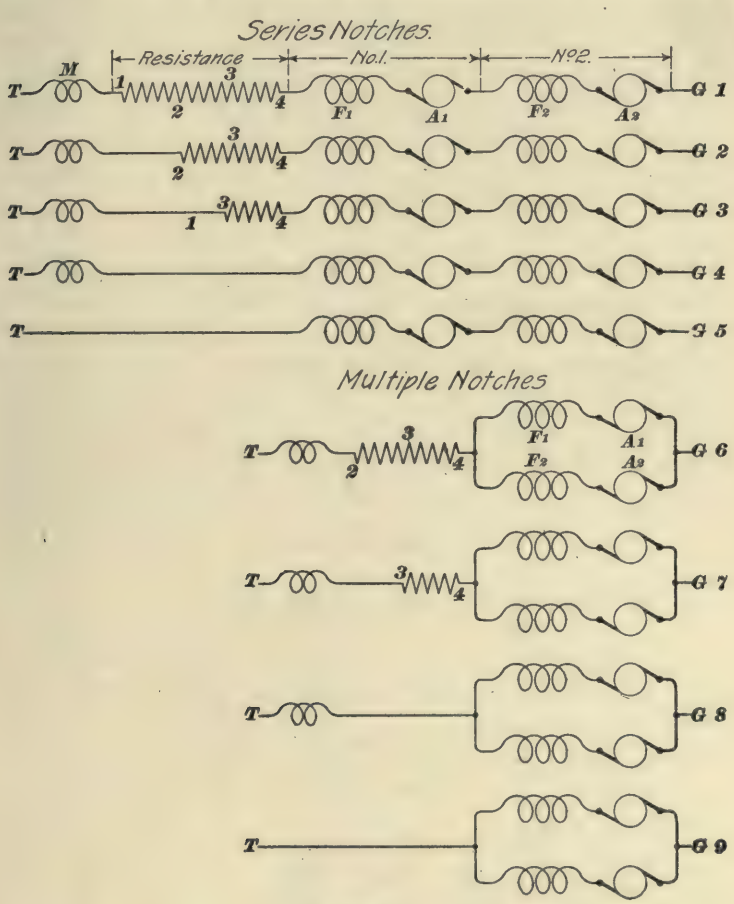



FIG. 17.

The combinations shown by *5* and *9* are those on which the car is usually run.

**22. Troubles.** — As in other controllers and wiring systems, trouble is liable to arise owing to short circuits, grounds, or open circuits. Grounds in the controller wiring

itself are not very liable to occur, because, as already pointed out, there are few internal connections in the controller and the absence of the connection boards simplifies matters. It will not be necessary to take up the troubles that are liable to occur in detail, because they are much the same as given for previous controllers, and if the student thoroughly understands these, together with the wiring diagram, Fig. 16, he should have no difficulty in accounting for any trouble that may arise.

**23. Starting-Coil Connections.**—In the diagrams representing the controller wiring, the starting coil is shown in the conventional form used for representing all kinds of resistances, but as the Johnson starting coil is somewhat different from other coils, its connections are given for both the 30 and 50 horsepower equipments. The coil used is the same in both cases; on the 30-horsepower motors, two coils to the car are used; on the 50-horsepower, three coils per car. Fig. 18 shows the connections for a car equipped with

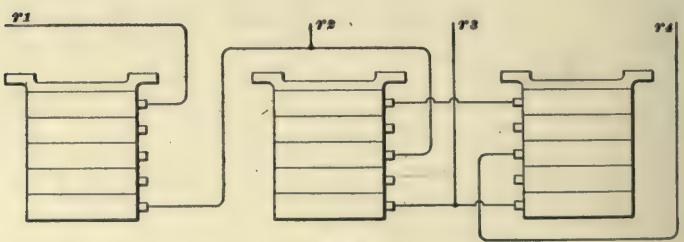



FIG. 18.

two No. 34 motors; between $r_1$ and $r_2$ is one complete coil that is cut out on the second notch; between $r_2$ and $r_3$ is another coil, the two halves of which are in multiple; this coil is cut out on the third notch; between $r_3$ and $r_4$ is another coil; this coil is cut out on the fourth notch. Fig. 19 is the connection for a car equipped with two 30-horsepower motors. Between $R_1$ and $R_2$ is a complete coil that is cut out on the second notch; between $R_2$ and $R_3$ is a section that is cut out on the third notch, leaving only one-quarter

of a whole coil in between posts $r_3$ and $r_4$, to be cut out on the fourth notch. On motors of greater capacities

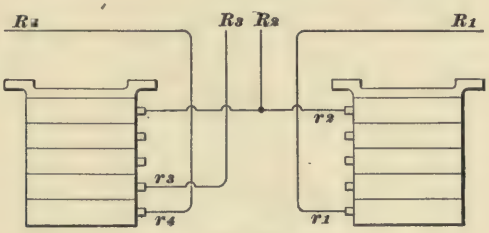



FIG. 19.

more coils are used in multiple; on motors of less capacity more coils are used in series.

A SERIES

OF

# QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

---

It will be noticed that the various Question Papers that follow have been given the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper, having the same section number as the Question Paper in which the questions or examples occur, has been carefully studied.

# MOTOR PRINCIPLES.

(PART 1.)

## EXAMINATION QUESTIONS.

(1) Why do motor leads swing back and forth when the current is thrown on and off?

(2) (*a*) How much current does a street-car lamp circuit take? (*b*) How much current does a standard 20-foot car require on a level?

(3) To what is the voltage of a trolley line due?

(4) What are lines of force?

(5) What is resistance?

(6) What is the effect of passing a current through a wire?

(7) What is a unit?

(8) Upon what does the strength of an electromagnet depend?

(9) What current is required in a street-car heater circuit?

(10) What is the effect of winding a wire up into a spiral?

(11) Why is the electromagnet preferable to the permanent magnet in a street-car motor?

(12) What would happen if an electrical circuit had very little resistance?



For notice of the copyright, see page immediately following the title page.

(13) (*a*) What is a single-acting pump? (*b*) What part of a dynamo generates pressure?

(14) What is the unit of current strength?

(15) (*a*) What is a magnet core? (*b*) When is iron said to be saturated?

(16) (*a*) What causes a street-car motor to heat? (*b*) Does the heating effect increase at the same rate as the current?

(17) What is the resistance of 1,000 feet of No. 10 B. & S. iron wire?

(18) Upon what does the direction of rotation in Fig. 18 depend?

(19) (*a*) What is the volt? (*b*) Why is it so called? (*c*) What is the unit of electrical pressure?

(20) (*a*) Does a pump generate water? (*b*) Does a dynamo generate electricity? (*c*) If not, what do they do?

(21) Give some of the effects of a current flowing in a wire.

(22) Why do we need units?

(23) How are the ampere and gallons per minute related?

(24) (*a*) What is the principle of a car heater? (*b*) What is the principle of an incandescent lamp?

(25) By what signs are the two sides of an electrical circuit distinguished?

(26) How does extreme heat affect magnetism?

(27) (*a*) What voltage is generally found on trolley lines? (*b*) on arc-light circuits? (*c*) on a storage cell?

(28) (*a*) What is the unit of weight? (*b*) What is the unit of pressure? (*c*) What is meant by 50 pounds boiler pressure?

(29) (*a*) What is an electromagnet? (*b*) What are some of its properties? (*c*) Upon what does its polarity depend?

(30) (*a*) What shape have the lines of force surrounding the wire carrying current? (*b*) How can we exactly double their number?

(31) What causes a fuse to blow?

(32) What voltage is likely to produce death?

(33) What is a solenoid?

(34) (*a*) Give your idea of resistance. (*b*) How does it affect current?

(35) What is a voltmeter?

(36) Why does a dusty rail make a car run slow?

(37) (*a*) What is a commutator? (*b*) For what is it used?

(38) (*a*) Upon what effect is motor action based? (*b*) Upon what effect may the determination of the ampere be based?

(39) (*a*) What are the advantages of hard steel for making permanent magnets? (*b*) What are the advantages of soft iron for electromagnets?

(40) What happens to the lamps when the engine runs away? Why?

(41) How do two wires carrying current act toward each other?

(42) Give a practical idea of the value of an ohm.

(43) Is carbon an insulator?

(44) What is meant by an *excited* motor field?

(45) How are voltage, current, and resistance related?

(46) What is the unit of resistance?

(47) (*a*) What is a conductor? (*b*) What is an insulator? (*c*) What is a feeder? (*d*) What is a trolley line breaker?

(48) Has copper more resistance than iron?

(49) Compare permanent magnets and electromagnets.

(50) (*a*) What is meant by inversely? (*b*) What is the resistance of an open circuit? (*c*) What is a short circuit?

(51) Give Ohm's law in your own words.

(52) Why are the filings not attracted to the center of the magnet?

(53) Why is the voltage low at the end of a line?

(54) What is a bar magnet?

(55) What is (*a*) a magnetic field? (*b*) a magnetic circuit?

(56) (*a*) What is a permanent magnet? (*b*) What are the poles of a magnet and how are they marked? (*c*) Why are they named poles?

(57) Tell what you know of the horseshoe magnet.

(58) What is the resistance (*a*) of a street-car lamp circuit? (*b*) of a 30-horsepower rheostat? (*c*) of the human body?

(59) Will a magnet attract brass or wood?

(60) Why not make a railway motor of horseshoe magnets?

(61) What is the effect of putting iron inside a spiral?

(62) Why is a fine watch less liable to lose its magnetism than a cheap one?

(63) (*a*) What is a reverse switch? (*b*) Of what use is a commutator on a motor?

(64) What is generally the voltage on suburban lines?

(65) Give in a few words the law of magnetic attraction and repulsion.

(66) In what units are voltage, current, and resistance expressed?

(67) What causes a motor armature to rotate?

(68) How many poles must a magnet have?

(69) Name some of the different uses to which electricity is put on a street car.

(70) How can you map out the lines of force of a magnet?

(71) Will magnetism pass through brass, leather, etc.?

(72) At what point do lines of force exert an outside influence?

(73) For what is a voltmeter used?

(74) Tell what you know of a ship's compass.

(75) Tell what you know about motor rotation.

# MOTOR PRINCIPLES.

(PART 2.)

## EXAMINATION QUESTIONS.

(1) What has speed to do with the effective resistance of a motor armature?

(2) What is meant by counter electromotive force?

(3) (*a*) How is ohmic resistance cut out? (*b*) Draw a diagram showing how this is done.

(4) What are shunts and loops used for?

(5) How is a permanent magnet made?

(6) Give an example of high induced electromotive force.

(7) Between what notches do controllers generally break down?

(8) (*a*) What is spurious resistance? (*b*) On what does it depend?

(9) What is a magnetic blow-out?

(10) When the controller drum is advanced one notch from the off position, what takes place?

(11) What are some of the objections to shifting cars?

(12) How does counter electromotive force affect the current?

(13) How does a current perform work?

(14) What does jerking indicate?



For notice of the copyright, see page immediately following the title page.

(15) Give two other names for counter electromotive force.

(16) On what does counter electromotive force depend?

(17) How does the wire in Fig. 2 first show evidence of current?

(18) (*a*) How should a controller be thrown from series to parallel? (*b*) Give the general effects of throwing a controller from series to parallel too quickly.

(19) How may lamps be used to take up a field discharge?

(20) Give an analogy showing the similarity in properties between water pressure and electrical pressure.

(21) (*a*) How are impressed and induced electromotive forces related when a circuit is made? (*b*) How are they related when it is opened?

(22) (*a*) What is the effect of weakening a motor field as regards the speed? (*b*) Why?

(23) Why is it unsafe to apply high voltage to an armature when it is not in motion?

(24) Why is counter electromotive force sometimes called spurious resistance?

(25) On what depends the amount of current that will go through each of two wires in multiple?

(26) What is the effect of doubling the cross-section of a wire?

(27) Where is most of the damage done when a controller is thrown off and on quickly?

(28) What prevents a car from starting with a jerk?

(29) (*a*) How much more resistance have two wires in series than the same two wires in multiple? (*b*) How much more ohmic resistance have two motors in series than two motors in multiple?

(30) (*a*) When are two wires said to be in series? (*b*) When are two wires said to be in multiple? Give sketches.

(31) (*a*) When are lamps in series? (*b*) When are they in multiple?

(32) (*a*) What is simple induction? (*b*) What is mutual induction?

(33) Give a general idea of induction.

(34) What is the difference between a shunt and a loop?

(35) Two motors in multiple take 40 amperes from the line. What will be the current in each?

(36) (*a*) When are two motors said to be in parallel? (*b*) Give a sketch showing two motors in parallel.

(37) (*a*) What is ohmic resistance? (*b*) On what does it depend?

(38) What is the effect of turning the drum of a controller too rapidly?

(39) On what does the voltage generated in a moving wire depend?

(40) Why does a steam engine do work in turning a dynamo armature?

(41) Give a rough sketch showing two motors in series.

(42) Give two combinations used in going from series to parallel.

(43) How does the cutting out of resistance affect the speed?

(44) What is a loop?

(45) Tell what you can of the experiment connected with Fig. 2.

(46) Why should the controller be given time on notches?

(47) What takes the place of ohmic resistance cut out by the controller?

(48) Why does a controller flash badly when quickly thrown on and off?

(49) Can an electromotive force exist in a wire through which no current flows?

(50) What effect has a magnetic field on an arc?

(51) What is a shunt?

(52) When are two motors said to be in series?

(53) What is the effect, as regards resistance, of doubling the length of a wire?

(54) What is the difference between a motor and a dynamo?

(55) What is self-induction?

(56) (*a*) What is an inductive path? (*b*) What is a non-inductive path?

(57) (*a*) What is a lightning arrester? (*b*) What is its principle?

(58) What is the difference in principle between the experiment of Art. **2** and an actual dynamo?

# CAR EQUIPMENT.

(PART 1.)

## EXAMINATION QUESTIONS.

(1) (*a*) Give the principal features of the Nuttall trolley stand. (*b*) What advantage does this stand offer in case a trolley pole becomes bent?

(2) If both flanges of a trolley wheel persist in wearing sharp, what is the trouble?

(3) Give the dimensions of an ordinary trolley pole.

(4) Name the principal parts of a trolley stand.

(5) (*a*) If the groove of a trolley wheel wears down to one side, what is the trouble? (*b*) How would you remedy the trouble?

(6) What points would you look for in selecting a harp?

(7) What is meant by the ground wire of a car, and how does the current get from this wire to the ground?

(8) (*a*) What is the objection to a very soft trolley wheel? (*b*) What is the objection to a hard trolley wheel?

(9) How often should a trolley wheel be oiled?

(10) Why is it not a good plan to heat trolley poles in order to straighten them?

(11) Of what different materials are trolley harps made?



For notice of the copyright, see page immediately following the title page.

(12) What causes tend to make a trolley wheel chatter?

(13) (*a*) What are trolley contact springs, and for what purpose are they used? (*b*) What would be the result if they were not used?

(14) What will be the result if a trolley wheel is not kept properly oiled?

(15) For what is the ferrule used?

(16) What kind of bushing is used for trolley wheels?

(17) Name the different devices used on a street car, giving them in the order in which the current flows through them from the trolley wire to the rail.

(18) Name the principal parts of the trolley.

(19) Give the principal points by which the Johnson trolley base differs from the T.-H. base.

(20) Give some of the causes that will make the trolley jump off a frog.

(21) How would you make a water-tight job where the trunk wiring passes through the roof of the car?

(22) What is a frog?

(23) What is meant by the bridge of a trolley car?

(24) What size should the trunk wire be when two 30-horsepower motors are used on the car?

(25) About what angle should the trolley pole ordinarily make with the roof of the car?

(26) Show how trunk wiring may be run in molding.

(27) How may the trunk wiring be attached to the trolley base?

(28) How can you tell whether the power is on or off by means of the sound made by the gears?

(29) Why should a car never be run with the pole slanting the wrong way?

(30) What is a good value for the pressure between the trolley and the wire?

(31) If the trolley should come off the wire, why should it never be replaced while the car is in motion?

(32) (*a*) What is the trunk wiring? (*b*) Describe how it is run from the trolley base to a point under the car floor.

(33) How will the trolley behave if the pressure against the trolley wire is too great?

(34) What size should the trunk wire be when two 50-horsepower motors are used on the car?

(35) Under what circumstances would you use molding for wiring a car?

(36) What is meant by the deck of a trolley car?

(37) What will happen if fuses of too large size are used?

(38) How is the arc broken in the Johnson fuse box?

(39) How is the arc broken in the General-Electric canopy switch?

(40) Why is copper wire used for fuses?

(41) Why should the canopy switch always be opened when fuses are replaced?

(42) About how often should a fuse require to be renewed under ordinary working conditions?

(43) Where are fuse boxes usually located?

(44) About what current would a 40-horsepower motor take at full load?

(45) What size copper fuse should be used with a 30-horsepower car equipment?

(46) How is the arc broken in the General-Electric fuse box?

(47) What size copper fuse should be used with 50-horse-power equipments?

(48) For what is a canopy switch used?

(49) Why is it better to connect canopy switches in series than in parallel?

(50) How would you replace a fuse in a Westinghouse fuse box?

(51) Why should twisted fuses not be used?

# CAR EQUIPMENT.

(PART 2.)

## EXAMINATION QUESTIONS.

(1) (*a*) Would an Ajax arrester work if set upside down? (*b*) Would it work if laid on its back?

(2) What is the effect of confusing the trolley and ground wires on the new type of General-Electric arrester?

(3) Of what material are starting coils usually made?

(4) (*a*) What would be the effect of setting a Garton arrester upside down, or laying it down? (*b*) Why?

(5) What are the main precautions to observe in loading an Ajax arrester?

(6) What is the effect of weakening a field?

(7) What is the general principle of action of an Ajax arrester?

(8) How can you prove that a full field gives more starting power than a shunted field?

(9) What is a charged pole, and what causes it?

(10) Why are both ohmic and spurious resistance necessary in a lightning-arrester circuit?

(11) (*a*) What is a starting coil? (*b*) What is it used for on a car?

(12) (*a*) What is a kicking coil? (*b*) In what branch of the circuit does it go?



For notice of the copyright, see page immediately following the title page.

(13) Why should all arrester wires be run as straight as possible?

(14) With what material is a Westinghouse starting coil insulated?

(15) What are the indications when a starting coil, properly used, heats too much?

(16) How would you set up a Garton arrester on a car?

(17) (*a*) How would you cut out the new type General-Electric arrester? (*b*) What directs the magnetism across the arc?

(18) Give a rough sketch showing the principle of the Garton lightning arrester.

(19) How would you cut out a Garton arrester?

(20) How is a shunt connected in relation to the field?

(21) Give a sketch showing how a Garton arrester is connected to the trolley wire.

(22) Show how an Ajax arrester should be connected to the trolley wire.

(23) (*a*) Is it advisable to run on resistance notches? (*b*) If not, why?

(24) Give a brief description of the Wurts arrester.

(25) What is the object of the coil in the Ajax arrester?

(26) Why should the shunt notch not be used when climbing grades?

(27) What must be done when an arrester becomes grounded?

(28) Show the internal connections of the older type of General-Electric arrester.

(29) Give a rough sketch of the internal connections in an Ajax arrester.

(30) Give a brief description of the new type of General-Electric arrester, and explain each part.

(31) (*a*) Will a Wurts arrester work upside down? (*b*) If not, why?

(32) What relation should the air gap in an arrester have to the motor insulation?

(33) How may a Wurts arrester be cut out?

(34) Why does the full field give a car more pulling power for a given current than a shunted field?

(35) (*a*) What is a shunt, and for what is it used? (*b*) Is the shunt notch a running notch?

(36) If two wires *a* and *b* are of 1 ohm resistance, (*a*) what is their resistance in series? (*b*) what is their resistance in multiple?

(37) How would you increase the current capacity of a starting coil?

(38) (*a*) What distinctive feature has the General-Electric arrester? (*b*) What puts out the arc?

(39) What is the effect of exchanging trolley and motor wires on an Ajax arrester?

(40) How would you test for a charged pole, and how could you get rid of it?

(41) When parts of a starting coil heat too much, how does it affect the starting of the car?

(42) What three conditions tend to break the arc in the Garton arrester?

(43) What is the effect of confusing the trolley and ground wires on the old type of General-Electric arrester?

(44) How would you make a simple kicking coil?

(45) (*a*) What is the thinnest air gap practicable for lightning arresters? (*b*) What is the thickest used?

# CAR EQUIPMENT.

(PART 3.)

## EXAMINATION QUESTIONS.

(1) How does a ground on the positive side of an armature affect the armature?

(2) What must always be done before putting in a fuse wire?

(3) What would be the effect of a ground between points *F.B.* and *S* in Fig. 8?

(4) What is meant by separate excitation?

(5) What causes a car to buck?

(6) How does a sudden reversal affect the relation between the line E. M. F. and the counter E. M. F.?

(7) What are the symptoms of a ground on the positive side of a fuse box?

(8) (*a*) How does a short-circuited shunt cause a car to act? (*b*) Why does it do so?

(9) Why are faults more apt to occur on a grounded circuit than on a metallic circuit?

(10) If a motorman reports a car slow, what should be done with it?

(11) What is the difference between a grounded circuit and a metallic circuit?

(12) (*a*) What is an open-circuited shunt? (*b*) How does it affect the field coils? (*c*) How does it affect the speed?



For notice of the copyright, see page immediately following the title page.

(13) (*a*) How would you temporarily get rid of a faulty shunt? (*b*) Would you report it?

(14) (*a*) What three classes of faults are likely to occur in connection with a trolley car? (*b*) Define each class.

(15) In how many ways is the loop circuit liable to be opened?

(16) If the current in any wire is doubled, by how much is the heat increased?

(17) What is the main distinction between a shunt and a loop?

(18) In the case of an open-circuited field loop, how can the car be made to start on the first notch?

(19) (*a*) What is meant by rheostat control? (*b*) What is a rheostat? (*c*) What is a starting coil?

(20) How does a loop or shunt help the change from series to parallel?

(21) (*a*) What are starting coils usually made of? (*b*) What two purposes do they serve?

(22) (*a*) What is the blow-out coil used for on a rheostat? (*b*) Show how you would connect one in circuit.

(23) Name the principal parts of the Thomson-Houston rheostat.

(24) What relation has the position of the reverse switch handle to the direction of motion of the car?

(25) Make a rough sketch showing the resistance and electrical connections of a Thomson-Houston rheostat.

(26) How does rheostat control compare with series-parallel control?

(27) Where is the rheostat generally placed (*a*) on a single-end car? (*b*) on a double-end car?

(28) Give a rough sketch of a single motor controlled by a single rheostat.

(29) What is meant by full field control?

(30) If the car backs up for both positions of the reverse handle, what is the matter?

(31) When a field has a loop wire, how many field leads are there?

(32) Name some of the disadvantages attending the use of shunts and loops.

(33) (*a*) How does a short-circuited shunt affect the armature? (*b*) Give reasons for your answer.

(34) What advantages has the metallic circuit over the ground-return circuit?

(35) What test proves whether a fault is an open-circuit or a short-circuit?

(36) (*a*) How should a car be run in order to save the resistance coils? (*b*) Give reasons for your answer.

(37) How do long use and abuse affect the condition of a rheostat?

# CAR EQUIPMENT.

(PART 4.)

## EXAMINATION QUESTIONS.

(1) (*a*) What is the most common cause of sparking in a railway motor? (*b*) In which direction should dynamo brushes be shifted to avoid sparking?

(2) (*a*) Why is it that a grounded armature runs with a jerky motion? (*b*) What quick test will tell whether an armature is short-circuited or not?

(3) (*a*) What would you do in case of a grounded fuse box? (*b*) How would you get rid of a ground on the lightning arrester?

(4) In connection with Fig. 1, (*a*) how does a ground between $T$ and $A+$ cause the car to act? (*b*) How could the exact position of such a ground be further determined?

(5) In connection with Fig. 1, (*a*) what is the effect of a ground on the $A-$ side of the armature? (*b*) What is the effect of a ground on the $A+$ side? (*c*) Explain the difference between the two.

(6) In Fig. 4, (*a*) which part of the motor is placed next the ground? (*b*) Why is a ground anywhere from $A+$ to $F+$ liable to do a great deal of harm?

(7) In Figs. 1, 5, and 6, (*a*) is there any positive method of locating an open circuit up to the point $P$? (*b*) If the fault is not located by the action of the car, what must be done next?



For notice of the copyright, see page immediately following the title page.

(8) (*a*) How do you determine whether the power is on the line or not? (*b*) Is the lamp-circuit test infallible? (*c*) If not, why?

(9) (*a*) In what three ways may an open circuit be traced to the brushes? (*b*) Why is it unwise to leave the traps up while working in a car?

(10) (*a*) What are dead rails, and how may they be caused? (*b*) What are bond wires or "bonds," and what causes them to break?

(11) (*a*) When is the roof wire apt to be the cause of an open circuit? (*b*) How do hood switches sometimes cause open circuits?

(12) In Fig. 5, (*a*) how does an open circuit between *K* and *o* make the car act? (*b*) How does the car act if the open circuit occurs between *o* and the reverse switch?

(13) (*a*) What is a line circuit-breaker? (*b*) Why are they used? (*c*) What rule should a motorman observe in passing over a breaker?

(14) (*a*) Why is it that a car will run through dust that it will not start in? (*b*) How would you get a car started on a dusty rail?

(15) (*a*) How would you locate the faulty coil in case of an open-circuited field? (*b*) How does cutting out a field coil affect the starting of the car?

(16) (*a*) Could a brush hammer being up cause an open circuit? (*b*) How can a tight brush cause an open circuit?

(17) (*a*) How would you get your car to the house in case of a grounded rheostat? (*b*) How would you get rid of a grounded field on a single-motor car?

(18) (*a*) What would you do first in case of a grounded reverse switch? (*b*) How would you cut out a defective reverse switch?

(19) In Fig. 1, (*a*) which does the current reach first—the field or the armature? (*b*) Does it make any difference which the current goes through first? (*c*) If so, give your reasons.

(20) (*a*) What is the effect of an open circuit in the armature winding? (*b*) Give reasons for your answer.

(21) Which do you consider the better plan of connections for a single-motor car, that shown in Fig. 1, or that shown in Fig. 4? Give reasons for your preference.

(22) (*a*) What is the effect of a ground on the loop wire when the car is in motion and running on the loop? (*b*) What is the effect if the car is standing still?

(23) (*a*) How can the effect of a ground on the positive field lead, in Fig. 4, be done away with? (*b*) How would you arrange to run the car ahead instead of back?

(24) (*a*) What is meant by "bucking"? (*b*) Why does the intensity of the bucking increase with the speed of the car?

(25) (*a*) What is the effect of a ground on the shunt when the car is running on the shunt? (*b*) What is the effect when the car is running, but not on the shunt?

(26) (*a*) What is the effect of a ground on the shunt if the car is standing still? (*b*) Is a ground on a shunt apt to give rise to more violent bucking than a ground on a loop? (*c*) If so, why?

(27) How may the trouble caused by a grounded loop wire be done away with?

(28) (*a*) What would be the symptom of a grounded brush holder? (*b*) What test would prove such to be the fault?

(29) How may a motorman improve the condition of a motor as regards sparking?

(30) In connection with Fig. 1, what is the effect of a ground on post No. *5*?

(31) (*a*) What is meant by a "loop" in speaking of a street-railway track? (*b*) Name and explain two sources of trouble incidental to running around a loop.

(32) Name some of the causes of failure in a street-car lamp circuit.

(33) What is the first place to inspect for an open circuit in the rheostat?

(34) What is the difference between a short circuit and an open circuit?

# CAR EQUIPMENT.

(PART 5.)

## EXAMINATION QUESTIONS.

(1) (*a*) How would a ground at $F_1+$ or $F_2+$, Fig. 16, affect the starting of the car? (*b*) What would be the effect if the fault showed up while the car was in motion? (*c*) Give your reasons.

(2) With the connections shown in Fig. 16, should the field be cut out whenever a faulty armature is cut out? Give reasons for your answer.

(3) (*a*) Where must a fault be in order to disable both ends of a car? (*b*) Can such a fault always be cut out by ordinary methods?

(4) (*a*) On what does the ability of a dynamo to generate depend? (*b*) What conditions are necessary in order that a street-car motor may generate?

(5) (*a*) When are two dynamos said to be in opposition? (*b*) When the motors on a car act as dynamos, are they in opposition?

(6) Explain how two motors may be used to brake a car.

(7) (*a*) What is the objection to the practice of braking with the motors? (*b*) What supplies the energy necessary to stop the car?

(8) (*a*) What is the effect of an open circuit at $c$ or $c_1$, Fig. 18? (*b*) Why does the motor with a weak field take more current than its mate?



For notice of the copyright, see page immediately following the title page.

(9) What is the main advantage of a double reverse switch?

(10) How can a field coil be cut out in case of a fault?

(11) In Figs. 29 and 30, what is the effect of confusing a shunt or a loop wire with a field wire?

(12) What would be the effect of a ground at *a*, Fig. 32?

(13) In Fig. 34, what is the effect of confusing the $A_1-$ and $A_2-$ leads?

(14) (*a*) Define *rheostat* and *controller*. (*b*) Is there any difference in their functions?

(15) What is a cut-out switch? Make a rough sketch of one.

(16) (*a*) How does the voltage divide between two motors in series? (*b*) Define *series control* and *multiple control*.

(17) Make a sketch showing the connections for one motor controlled by one rheostat.

(18) Make a sketch showing the connections for one motor controlled by two rheostats.

(19) Make a sketch showing the connections for two motors controlled by one rheostat and one reverse switch.

(20) (*a*) Which end of a double-end car is called the *front end?* (*b*) What advantage is there in agreeing on which is to be called the *front end?*

(21) (*a*) Are the two motors on a car connected exactly alike, and if not, why? (*b*) In case the two motors opposed each other, what would you do to right matters?

(22) (*a*) In Fig. 16, how would you cut out a motor in case of a bad field? (*b*) In cutting out No. 1 field, would you disconnect the armature also, and if so, why?

(23) (*a*) Show how a fuse box may be wrongly connected. (*b*) Does it matter at which side the current enters a fuse box?

(24) (*a*) In Fig. 3, what is the effect of interchanging the *L* and *K* wires? (*b*) How does such a change affect the starting power and speed of the car?

(25) (*a*) In Fig. 4, what is the effect of interchanging the shunt and field wires? (*b*) How does such a change affect the starting power and speed of the car?

(26) How does an interchange of the shunt and field wires, Fig. 4, affect the shunt?

(27) (*a*) What two classes of wrong connection can be made in the field coils? (*b*) What is an external or outside connection? (*c*) an internal or inside connection?

(28) (*a*) What happens, Fig. 5 (*b*), if the *F*+ and *F*— field leads become confused? (*b*) How does this affect the indication of the reverse lever?

(29) (*a*) How many field coils are there on most modern railway motors? (*b*) Are these coils alike?

(30) (*a*) How could you distinguish the inside end of a field coil from the outside end? (*b*) Are like ends or unlike ends connected together inside the motor?

(31) (*a*) How can a field coil be placed in the wrong position? (*b*) If the current enters one coil at the inside end, how should it enter its neighbor?

(32) If one coil of a motor is put in or connected up wrongly, what is the effect as far as the speed is concerned?

(33) In Fig. 2, what effect has the interchange of the *F*— and *G* wires?

(34) In Fig. 8, what effect has an interchange of the *A*— and *G* wires?

(35) (*a*) Are the indications of an open circuit, as a rule, violent? (*b*) What generally calls attention to the fact that an open circuit exists?

(36) (*a*) When a field is cut out, Fig. 19, should the shunt wire be disconnected also? (*b*) Can one large shunt be used instead of two small ones, and if not, why?

(37) (*a*) What is the effect of an open circuit at $c_2$ or $c_3$, Fig. 18? (*b*) What takes place as soon as the loop plate is reached? Give reasons for your answer.

(38) (*a*) Why is the indication of a grounded or open-circuited armature more pronounced on a double-motor than on a single-motor car? (*b*) In case of either, what should be done, and what precautions should be observed in doing it?

(39) In Fig. 9, what effect has an interchange of the $A+$ and $G$ wires?

(40) In Fig. 10, what effect has an interchange of the $A+$ and $F-$ wires?

(41) In Fig. 11, what effect has an interchange of the $A+$ and $A-$ wires?

# CAR EQUIPMENT.

(PART 6.)

## EXAMINATION QUESTIONS.

(1) (*a*) What are the principal parts of a motor? (*b*) Of what metal is the field frame of railway motors usually made, and why is this metal selected?

(2) Give the following particulars relating to the G. E. 1000 motor: (*a*) number of pole pieces; (*b*) number of turns in field coil and size of wire; (*c*) size of wire and number of turns per coil in armature; (*d*) number of coils in armature; (*e*) number of slots in armature.

(3) (*a*) How would you set about taking an armature out of a G. E. 1000 motor? (*b*) How would you protect the armature in so doing?

(4) (*a*) Why is the armature core of a motor built up out of plates? (*b*) What is the name given to the local currents that would circulate in the core if it were not laminated?

(5) (*a*) What is the commutator used for? (*b*) Are the copper bars supposed to touch one another? (*c*) What is the best material for insulating commutators, and why should the insulation between the bars not be too hard?

(6) (*a*) Why does a journal or bearing run hot? (*b*) How would you treat a hot box? (*c*) What would you do in case the axle were cut?

(7) Of what material are railway-motor brushes made, and why is this particular material used?



For notice of the copyright, see page immediately following the title page.

(8) (*a*) Between what limits does the load on a railway motor vary in service? (*b*) Would a brush-shifting device be of any use on a car, and, if so, why?

(9) (*a*) What is the full-load current of a 100-horsepower, 100-volt motor? (*b*) What is the full-load current of a 100-horsepower, 500-volt motor?

(10) (*a*) What is a radial brush holder? (*b*) Is the G. E. 1000 brush holder a radial one? (*c*) What is the advantage of the radial type of brush holder?

(11) (*a*) How would you set the brushes on a G. E. 1000 commutator? (*b*) What is one of the causes of chattering brushes?

(12) (*a*) Why is the pinion-end bearing made larger than that on the commutator end? (*b*) What are the dimensions of the G. E. 1000 bearings?

(13) (*a*) Why is an axle gear made in two halves? (*b*) What are gears and pinions generally made of? (*c*) What is meant by the gear reduction?

(14) (*a*) What are the advantages and disadvantages of a rawhide pinion? (*b*) How does a rawhide pinion affect the life of a gear?

(15) (*a*) What causes gearing to click or knock? (*b*) What would help you to decide as to whether the fault were in the gear or the pinion?

(16) What is the horsepower of the G. E. 52 motor? the G. E. 800 motor? the G. E. 1000 motor?

(17) (*a*) What is meant by a horsepower? (*b*) What is a foot-pound? (*c*) Are both units dependent on time?

(18) (*a*) What is a watt? (*b*) How many watts are there in a horsepower? (*c*) How are foot-pounds per second converted into watts? (*d*) How are watts converted into foot-pounds per second?

(19) Give the following particulars relating to the G. E. 52 motor: (*a*) number of pole pieces; (*b*) number of slots in armature; (*c*) number of coils on armature; (*d*) number of bars in commutator; (*e*) size of wire on armature; (*f*) number of turns per armature coil.

(20) (*a*) Briefly describe the G. E. 800 motor. (*b*) Is this motor intended to be worked on from below, and, if not, why?

(21) Give the following particulars relating to the G. E. 800 motor: (*a*) number of field coils; (*b*) method of holding field coils in place; (*c*) number of turns in each field coil; (*d*) number of slots in armature core; (*e*) number of bars in commutator; (*f*) number of turns per armature coil; (*g*) size of armature wire.

(22) What is the handhole under the commutator in railway motors used for?

(23) (*a*) How would you tell an armature lead from a field lead? (*b*) What do you think would be the result of confusing them?

(24) Of what use is the shield on an armature?

(25) (*a*) What two forces tend to throw the coils of an armature out of place? (*b*) If the coils do raise a little, what is liable to happen?

(26) (*a*) About how many amperes are allowed per square inch of brush surface when carbon brushes are used? (*b*) How many square inches of brush surface would be required for 800 amperes?

(27) (*a*) What brush-holder trouble is armature end play liable to cause? (*b*) How could you make sure that such trouble could not occur? (*c*) Why is jacking up the truck and running the motors an unreliable test?

(28) (*a*) How would you test the bearings on a newly equipped car? (*b*) How does a hot box affect the power required to run the car?

(29) (*a*) How many teeth are there in the gear and pinion of the G. E. 52 motor? (*b*) What is the reduction?

(30) (*a*) How would you fit a 4″ axle bearing to a $3\frac{5}{8}$″ axle? (*b*) What is meant by "packing a box" and how is it done?

(31) (*a*) If oil is used in an axle box, what must be used with it? (*b*) What two kinds of motor grease are used in cold climates, and explain why it is necessary to have two kinds?

(32) (*a*) If a hot armature box is not found in time, what is liable to happen? (*b*) What do you consider the first relief to a hot box? (*c*) How can a pitman generally tell if a brass is cutting?

(33) (*a*) How many teeth are there in the gear and pinion of the G. E. 800 motor? (*b*) What is the reduction?

(34) Why should the wood used for brush-holder yokes be very carefully selected?

(35) Have you ever done work on the G. E. 1000 motor; if so, what do you think are its good and its bad points?

(36) (*a*) Have you ever worked on a G. E. 52 motor? (*b*) What do you consider its good and its bad points? (*c*) What do you think of the method of holding in the field coils?

# CAR EQUIPMENT.

(PART 7.)

## EXAMINATION QUESTIONS.

(1) (*a*) What is the condition of affairs when the K2 controller is on the fourth notch? (*b*) Give a description of what occurs on the fifth notch.

(2) Suppose a car fails to start on the first notch on both controllers, but starts on the second notch on both, where would you look for the trouble?

(3) (*a*) What connections are made when the drum of the K2 controller is on the ninth position? (*b*) What is the state of affairs when the drum is on the last notch?

(4) Why is it necessary that the controller should be built so that the drum cannot be moved past the fifth position whenever either of the cut-out switches is thrown up?

(5) Draw a set of simple diagrams illustrating the combinations made by the K2 controller on each of the different positions.

(6) Why will a ground on finger block $A_1$, or motor brush to which $A_1$ wire runs, not allow the car to be run ahead, but will, under certain conditions, allow No. 2 motor to become a generator and violently check the speed of the car?

(7) (*a*) How many wires are there running the full length of a car equipped with K2 controllers? (*b*) Why are the armature wires in one controller reversed?



For notice of the copyright, see page immediately following the title page.

(8) (*a*) If No. 1 motor has an open-circuited field, how will the car act when the controller reaches the fifth notch? (*b*) How will the car act if the open circuit is on the No. 2 motor field?

(9) Why is it not safe to leave a controller on a resistance notch for any length of time?

(10) (*a*) How many positions are there on a K2 controller? (*b*) Which notches of a K2 controller are running notches?

(11) (*a*) How many resistance notches are there on a K2 controller? (*b*) How many notches are there altogether?

(12) (*a*) What two things does the power drum do? (*b*) Give a general description as to how the power drum of the K2 controller is constructed.

(13) How could you remove the effect of any ground between the lower block *19* and block $E_1$, Fig. 18?

(14) What would happen if both controllers were left at the go-ahead position and an attempt were made to operate the car from either end?

(15) Draw a series of simple diagrams showing the combinations for the various steps of the K11 controller.

(16) (*a*) For what is the magnetic blow-out used? (*b*) For what are the cut-out switches used? (*c*) For what is the interlocking device used?

(17) If both motors obey the reverse switch on one end, but disobey it on the other, where and how would you remedy the trouble?

(18) Why is it very bad practice to move the controller around to the ninth notch when either motor has an open-circuited field?

(19) Can a ground between top block $E_1$ and top block *15*, Fig. 18, be removed by means of the cut-out switches?

(20) (*a*) If one motor has an open-circuited shunt, how is the armature of the other motor affected? (*b*) Why does the field of the motor with the open-circuited shunt heat up?

(21) How would you cut out a controller in case of a ground on the blow-out magnet coil so that the car could be run in from the other controller?

(22) (*a*) For what size of motor is the K2 controller intended? (*b*) Give the names of the main parts that go to make up a K2 controller.

(23) A car fails to start on the first notch but starts on the second. Name three different causes that may make the car act in this way.

(24) (*a*) Why are several resistance notches necessary on a controller? (*b*) Give sketches of a two-part resistance; (*c*) of a three-part resistance.

(25) Why is a ground between field lead $E_1$ on motor No. 1 and armature lead $AA_2$ on motor No. 2 not apt to be noticed until the power drum is thrown to multiple? Illustrate by means of a diagram.

(26) What two features distinguish the K11 controller from the K2?

(27) If a car fails to start until the fourth notch is reached, what is the trouble?

(28) If a car loses the power on the third notch, what is the trouble?

(29) (*a*) What is the general construction of the reverse drum on a K2 controller? (*b*) Does it reverse the current through the armatures or through the field of the motors?

(30) If a car starts all right with both motors cut in, but disobeys the reverse switch at both ends, what is the trouble?

(31) (*a*) What parts of the car wiring carry current no matter which controller is in use? (*b*) Do the hose wires carry current throughout their entire length?

(32) (*a*) How many running notches has the K11 controller? (*b*) What are the numbers of these notches?

(33) What would happen if the controller connections of both motor fields were reversed?

(34) How many running notches are there on a K2 controller?

(35) If a car obeys the direction of the reverse handle at one end but not at the other, what should be done?

(36) (*a*) How are the various notches indicated on the top of the controller? (*b*) How are the running notches distinguished from the others?

(37) (*a*) What is the trouble if the car loses the power completely on the fourth notch? (*b*) What is the trouble if there is only a partial loss of power?

(38) (*a*) Name some of the different types of G. E. controllers. (*b*) What are the meanings of the letters denoting the different types as given by the General Electric Company?

(39) Give a sketch of a K2 connecting board and letter the different connecting posts as they appear on the controller.

(40) Give sketches indicating the positions of the K2 cut-out switches (*a*) when both motors are in; (*b*) when No. 1 motor is cut out and No. 2 motor cut in; (*c*) when No. 2 motor is cut out and No. 1 motor cut in.

# CAR EQUIPMENT.

(PART 8.)

## EXAMINATION QUESTIONS.

(1) (*a*) Would you call the Westinghouse No. 3 motor a waterproof motor, and if not, why? (*b*) How do you explain its good record for holding its own against slush and water?

(2) (*a*) Where is the neutral line on a Westinghouse No. 3 motor? (*b*) Where is it on a General Electric 800 motor? (*c*) Are the brushes on a railway motor always situated at the neutral points?

(3) (*a*) Do the coils attached to bars passing under the brushes cut many lines of force? (*b*) Why is a lead of one-eighth given to the Westinghouse No. 3 armature connections? (*c*) Why is such a lead unnecessary on a General Electric 800 armature?

(4) How would you count off a 99-slot armature to connect at the commutator?

(5) (*a*) How does a change in the gear ratio affect the current used by a car? (*b*) How does it affect the speed?

(6) Have you ever had any experience with the Westinghouse 12A motor? If so, state what you consider its strong and its weak points.

(7) (*a*) What main points of advantage has the Westinghouse No. 12A motor over the Westinghouse No. 3? (*b*) What great advantage has a coil-wound armature?



For notice of the copyright, see page immediately following the title page.

(8) How many coils and slots has the Westinghouse 12A armature?

(9) (*a*) What is the "dummy" or "dead" coil of a 12A armature, and why does it occur? (*b*) What is the peculiarity of the wire used on the 12A field coil?

(10) (*a*) How will a ground at *2*, Fig. 30, cause a car to act? (*b*) at *3*? (*c*) at *4*? (*d*) at *5*? (*e*) at *6*?

(11) (*a*) Can all grounds be cut out by means of the cut-out switches? (*b*) If not, which grounds cannot be cut out?

(12) (*a*) What is meant by a ventilated armature core? (*b*) Why does the armature of a railway motor, as a rule, run cooler than the field coils?

(13) (*a*) How many power-drum fingers has the Westinghouse 28A controller? (*b*) With one motor cut out, on what notch does this controller start a car?

(14) Give a sketch of the Westinghouse 28A controller power drum, indicating the positions by dotted lines.

(15) How does the 28A reverse switch differ in general from that of the K2 controller?

(16) (*a*) Through what part of the motor is the current reversed by the 28A reverse switch? (*b*) What part of the motor, field or armature, is next to ground?

(17) (*a*) Describe, briefly, the 28A cut-out. (*b*) Make a sketch showing the connections of the 28A cut-out when both motors are in use.

(18) Make a sketch showing the 28A cut-out, and give the path of the current when No. 1 motor is cut out.

(19) Make a sketch showing the 28A cut-out with No. 2 motor cut out, and give the path of the current.

(20) (*a*) How many positions are there on the 28A controller? (*b*) How many notches?

(21) (*a*) How many running notches are there on the 28A controller? (*b*) What are the numbers of these notches?

(22) Give diagrams showing the connections on each of the running notches of the 28A controller.

(23) (*a*) What peculiarity is there about the 28A controller as to the method of placing the resistance coils? (*b*) Why is resistance cut in after leaving the fourth notch?

(24) How many wires run the full length of the car in the 28A wiring plan?

(25) (*a*) In what part of the circuit is the 28A blow-out coil placed? (*b*) Is this a good idea?

(26) (*a*) Which motor is ordinarily called the No. 1 motor? (*b*) Does it ever bother a motorman to locate his No. 1 motor?

(27) (*a*) What is the standard gear ratio of the No. 3 motor? (*b*) How many teeth are there in the pinion? (*c*) How many in the axle gear?

(28) (*a*) What is the general effect of a wrong internal field connection? (*b*) Make a rough sketch showing correct internal field connections for the Westinghouse No. 3 motor.

(29) (*a*) How does decreasing the turns per coil of an armature affect the speed of a car? (*b*) How does it affect the current?

(30) (*a*) How many coils, slots, and commutator bars has the Westinghouse No. 3 armature? (*b*) How many turns per coil are there ordinarily? (*c*) Does this number vary?

(31) (*a*) What size of wire is used on the Westinghouse No. 3 three-turn armature? (*b*) What is the size used on a four-turn armature?

(32) (*a*) How is the Westinghouse No. 3 armature supported from the motor frame? (*b*) In what places is wear likely to allow the pole pieces and armature to come in contact?

(33) Give the following particulars relating to the Westinghouse No. 3 motor: (*a*) size of bearings; (*b*) turns on each field coil when No. 6 wire is used; (*c*) turns per field coil when No. 5 wire is used.

# CAR EQUIPMENT.

(PART 9.)

## EXAMINATION QUESTIONS.

(1) (*a*) How are the blow-out coils on the type S Walker controller arranged? (*b*) Are these coils left in circuit all the time?

(2) (*a*) How many notches are there on the type S reverse drum? (*b*) Give the different notches and tell the combinations on each.

(3) Can a car be brought to a stop on a grade by making the motors act as dynamos, and if not, why?

(4) (*a*) How would you make an ordinary reversal with the type S controller? (*b*) How would you make a dynamo stop; i. e., a stop when the motors are made to act as dynamos?

(5) If the brushes of a motor spark when running one way, what is probably the matter?

(6) (*a*) What is claimed to be the advantage of raised commutator ears? (*b*) Do they protect the end of the winding?

(7) (*a*) What type of armature has the Walker 30-horsepower motor? (*b*) How many slots are there in the core? (*c*) How many coils are there?

(8) How is the inside of a Walker motor ventilated?



For notice of the copyright, see page immediately following the title page.

(9) How does the yoke of the Walker motor differ from that of the Westinghouse No. 3?

(10) (*a*) How could you tell the inside from the outside ends on a Walker field coil? (*b*) Which ends go together when the coils are connected up?

(11) Give one condition under which the brushes will spark when the car runs in either direction.

(12) (*a*) How are the two shells of a Walker motor held together? (*b*) What are the peep holes in the end of the casing used for?

(13) (*a*) By what means is the Walker armature retained in the top shell when the bottom field is lowered? (*b*) What must be done in order to let down the bottom shell?

(14) What is the main peculiarity of the Walker suspension?

(15) Describe the operation of the Walker magnetic interlocking device.

(16) Why do suspension springs sometimes give out a rattling noise?

(17) How many turns and what size of wire is used in winding the field coils of the Walker 30-horsepower motor?

(18) (*a*) How many castings are there on the power drum of the type S controller? (*b*) Why are the $a_{4\frac{1}{2}}$ and $a_{9\frac{1}{2}}$ tips made narrower than the $a_4$ and $a_9$ tips?

(19) How many commutator bars should there be between the centers of brushes on the Walker 30-horsepower motor?

(20) (*a*) How many notches are there on the type S controller? (*b*) How much of the starting coil is cut in on the first multiple notch?

(21) (*a*) If one motor is cut out, on which notch does the car start? (*b*) Why can it not start on any of the series-notches?

(22) (*a*) What must be done in order to make a street-car motor generate? (*b*) State two changes, either of which will make it generate.

(23) Why is a blow-out coil with an iron core left in circuit all the time?

(24) How would you stop a car backing down a grade, assuming the trolley pole to be off and the hand-brakes out of order?

(25) (*a*) How many fingers are there on the type S reverse switch? (*b*) How many of these are used in reversing the car? (*c*) What are the two extra fingers provided for?

# CAR EQUIPMENT.

(PART 10.)

## EXAMINATION QUESTIONS.

(1) How is the armature of the Johnson No. 20 motor retained in the top half of the frame when the lower half is swung down?

(2) What is the object in using a paper lining between the commutator shell and the shaft?

(3) (*a*) What type of field coil has the No. 20 motor? (*b*) How many turns and what size of wire are used in each coil? (*c*) How are the lugs on the coil marked?

(4) Describe the No. 20 brush holder, giving the method of supporting and adjusting it.

(5) (*a*) How many slots has the No. 34 armature? (*b*) How many single coils? (*c*) How many commutator bars? (*d*) How many complete coils? (*e*) How many wires are there in each slot? (*f*) What size of wire is used?

(6) How does the No. 34 field coil differ from the No. 20?

(7) (*a*) How many teeth has the pinion of the No. 20 motor? (*b*) How many teeth has the axle gear? (*c*) What is the gear ratio? Show how to get it.

(8) Name some of the principal points wherein the Johnson No. 34 controller differs from the General Electric K2 controller.



For notice of the copyright, see page immediately following the title page.

(9) (*a*) What size of wire is used on the blow-out coil of the No. 34 controller? (*b*) How many turns are there?

(10) (*a*) How are the motors cut out on the No. 34 controller in case either of them becomes disabled? (*b*) Is it necessary to open the controller in order to cut out a motor?

(11) (*a*) Make a sketch showing the combinations made on the various notches of the No. 34 controller. (*b*) Which of these are the running notches?

(12) Referring to Fig. 16, give the path of the current when the power drum is on the sixth notch and the reverse lever at the "Ahead No. 1" position.

(13) Why are notches *5* and *9* to be preferred to *4* and *8* as running notches on the No. 34 controller?

(14) (*a*) How many resistance boxes are used with two No. 20 motors? (*b*) How many boxes are used with two No. 34 motors?

(15) Give a sketch showing how the starting coils are connected up for two 30-horsepower motors.

(16) Give a sketch showing how the resistance coils are connected for two 50-horsepower motors.

(17) What is there peculiar about the position of the finger board and the location of the fingers in the No. 34 controller?

(18) (*a*) Is the third notch of the No. 34 controller a running notch, and if not, why? (*b*) Why is it bad practice to run on notches that are not running notches?

(19) (*a*) What motor does the upper part of the reverse drum on a No. 34 controller control? (*b*) What are the internal connections of the controller?

(20) Give the dimensions of the No. 20 axle bearings.

(21) What is a good rule to follow in connecting up a set of field coils?

(22) How are the armature leads of the Johnson motors secured to the commutator bars?

(23) How are the field coils of the Johnson No. 20 motor secured in place?

(24) Referring to Fig. 16, give the path of the current on the eighth notch when the reverse switch is at the "Ahead" position.

(25) Give the path of the current on the sixth notch and with the reverse drum at the "Back No. 2" position.

# INDEX.

NOTE.—All items in this index refer first to the section (see Preface, Vol. 1) and then to the page of the section. Thus, "Shunts 4 31" means that shunts will be found on page 31 of section 4.


| A. | Sec. | Page. |
|---|---|---|
| Advantages of shunts | 5 | 12 |
| Ajax arrester, Connections for | 4 | 20 |
| " lightning arrester | 4 | 5 |
| " " " Principle of | 4 | 8 |
| Ampere | 1 | 4 |
| " Application of | 1 | 6 |
| Anderson trolley base | 3 | 15 |
| Appliances, Car | 3 | 1 |
| Application of the ampere | 1 | 6 |
| " " " ohm | 1 | 8 |
| " " " volt | 1 | 4 |
| Armature and commutator, Westinghouse No. 3 | 10 | 6 |
| " connections, Westinghouse No. 3 | 10 | 7 |
| " G. E. 52 | 8 | 40 |
| " G. E. 800 | 8 | 43 |
| " G. E. 1000 | 8 | 6 |
| " Grounds in | 6 | 5 |
| " Johnson No. 20 motor | 12 | 4 |
| " " No. 34 motor | 12 | 11 |
| " Open circuit in | 6 | 22 |
| " Walker 30 H. P | 11 | 6 |
| " Westinghouse 12A | 10 | 19 |

| B. | Sec. | Page. |
|---|---|---|
| Bar magnet | 1 | 13 |
| Bearings, G. E. 800 | 8 | 44 |
| " G. E. 1000 | 8 | 19 |
| " Johnson No. 20 motor | 12 | 8 |
| " " No. 34 motor | 12 | 13 |
| " Walker 30 H. P | 11 | 10 |
| " Westinghouse No. 3 | 10 | 6 |
| Blow-out, Magnetic | 2 | 27 |
| Bonnet switches (see "canopy switches"). | | |
| Braking action of motors | 7 | 30 |
| Bridge, Trolley | 3 | 21 |
| Brush holder, G. E. 52 | 8 | 41 |
| " " G. E. 1000 | 8 | 14 |
| Brush holder, Johnson No. 20 motor | 12 | 7 |
| " " " No. 34 motor | 12 | 13 |
| " " Walker 30 H. P | 11 | 8 |
| " " Westinghouse 12A | 10 | 20 |
| " " " No. 3 | 10 | 14 |
| " holders | 8 | 12 |
| Brushes, Commutator | 1 | 25 |
| " Open circuit at | 6 | 18 |

| C. | Sec. | Page. |
|---|---|---|
| Canopy switch, General Electric | 3 | 28 |
| " " Johnson | 3 | 31 |
| " " Westinghouse | 3 | 27 |
| " switches | 3 | 25 |
| Car-wiring diagram for K2 controller | 9 | 28 |
| " " " 28A controller | 10 | 36 |
| Care of trolley | 3 | 20 |
| Cars, Slow running of | 5 | 15 |
| Causes of slow running | 5 | 15 |
| Change in gear reduction | 8 | 27 |
| Charged poles | 4 | 23 |
| Classification of General Electric controllers | 9 | 1 |
| Closed magnetic circuit | 1 | 13 |
| Combination cut-out, Walker type S controller | 11 | 21 |
| " reverse switch and cut-out, Johnson type 34 controller | 12 | 17 |
| Commutator | 1 | 24 |
| " G. E. 1000 | 8 | 9 |
| " segments | 1 | 25 |
| Conditions required for generation of E. M. F | 7 | 28 |
| Connecting board K2 controller | 9 | 25 |
| Connections for Ajax arrester | 4 | 20 |
| " " Garton arresters | 4 | 3 |

| | Sec. | Page. |
|---|---|---|
| Connections for General Electric arrester.. | 4 | 17 |
| " " General Electric arrester, Early type... | 4 | 18 |
| " " Westinghouse arrester..... | 4 | 16 |
| " " Wurts lightning arrester..... | 4 | 12 |
| " Motor..... | 1 | 27 |
| " of fuses, Factors determining..... | 3 | 33 |
| Construction of commutator, G. E. 1000 motor..... | 8 | 11 |
| Contact springs..... | 3 | 5 |
| Control, Old-rheostat..... | 5 | 1 |
| Controller 28A, Car-wiring diagram..... | 10 | 36 |
| " " Cut-out..... | 10 | 25 |
| " " General plan of connections... | 10 | 29 |
| " " General remarks on..... | 10 | 39 |
| " " Grounds in connection with.. | 10 | 42 |
| " " Internal connections of.... | 10 | 27 |
| " " Reverse switch | 10 | 23 |
| " Johnson type 34..... | 12 | 13 |
| " K11..... | 9 | 45 |
| " Walker type S..... | 11 | 13 |
| " Westinghouse 28A.... | 10 | 20 |
| Controllers, Johnson..... | 12 | 13 |
| " Uses of..... | 9 | 2 |
| Copper fuses for 30 H. P. equipment ..... | 3 | 34 |
| " " " 50 H. P. equipment..... | 3 | 34 |
| Core..... | 1 | 17 |
| Counter E. M. F. and speed..... | 2 | 6 |
| " Electromotive force.... | 2 | 1 |
| Current..... | 1 | 4 |
| " Effects of..... | 1 | 5 |
| " paths and combinations, Walker type S controller..... | 11 | 24 |
| " Variation of with resistance..... | 1 | 10 |
| " Variation of with voltage..... | 1 | 9 |
| Cut-out, 28A controller..... | 10 | 25 |
| Cutting out resistance..... | 2 | 17 |

**D.**

| | Sec. | Page. |
|---|---|---|
| Dead rails..... | 6 | 19 |
| Details of cut-out switch K2 controller..... | 9 | 21 |
| " relating to trunk wiring | 3 | 24 |
| Determination of motor current ..... | 3 | 35 |
| Directions for mounting and oiling trolley..... | 3 | 20 |
| Distinction between dynamos and motors..... | 2 | 3 |
| " between loops and shunts..... | 5 | 17 |
| Double reverse switch, Equipment with..... | 7 | 24 |
| " " switch with shunt and loop | 7 | 31 |
| " " switch with shunt and loop, Wrong connections of..... | 7 | 35 |
| Duncan trolley base..... | 3 | 15 |
| Dusty rails..... | 6 | 17 |
| Dynamo, Picking up of..... | 7 | 27 |
| Dynamos and motors, Distinction between..... | 2 | 3 |

**E.**

| | Sec. | Page. |
|---|---|---|
| Early type General Electric arrester, Connections for..... | 4 | 18 |
| " " General Electric lightning arrester | 4 | 14 |
| Effect of changing gear reduction..... | 8 | 24 |
| " " quick handling..... | 2 | 18 |
| Effects of current..... | 1 | 5 |
| " " overloading motors and resistance..... | 4 | 27 |
| " " poor bonding..... | 6 | 19 |
| Electrical and mechanical units of power..... | 8 | 34 |
| " units..... | 1 | 1 |
| Electromagnet..... | 1 | 14 |
| Electromagnets, Comparison with permanent magnets..... | 1 | 18 |
| E. M. F., Counter..... | 2 | 1 |
| " " " Generation of..... | 2 | 1 |
| Equipment with double reverse switch..... | 7 | 24 |
| Examples of inductive effects in motor circuits..... | 2 | 31 |
| Explanation of loop..... | 2 | 8 |
| " " shunt..... | 2 | 7 |

**F.**

| | Sec. | Page. |
|---|---|---|
| Factors determining the length of fuses..... | 3 | 33 |
| Faults in shunts..... | 5 | 15 |
| Ferrule, The..... | 3 | 3 |
| Field coil, G. E. 800..... | 8 | 43 |
| " " Johnson No. 20 motor | 12 | 6 |
| " " " No. 34 motor | 12 | 11 |

| | Sec. | Page. |
|---|---|---|
| Field coil, Walker 30 H. P. | 11 | 7 |
| " " Westinghouse No. 3. | 10 | 11 |
| " coils, G. E. 52 | 8 | 40 |
| " " G. E. 1000 | 8 | 4 |
| " connections, Wrong | 10 | 13 |
| " next to ground | 6 | 9 |
| " Open circuit in | 6 | 24 |
| " Westinghouse 12A | 10 | 20 |
| Frame, G. E. 52 | 8 | 36 |
| " G. E. 800 | 8 | 42 |
| " G. E. 1000 | 8 | 1 |
| " Johnson No. 20 motor | 12 | 2 |
| " " No. 34 motor | 12 | 9 |
| " Walker 30 H. P. | 11 | 1 |
| " Westinghouse 12A | 10 | 17 |
| Frog and trolley, Relation between | 3 | 17 |
| Frogs | 3 | 17 |
| Fuse box, General Electric | 3 | 37 |
| " " Johnson | 3 | 38 |
| " " Use of | 3 | 33 |
| " " Walker | 3 | 38 |
| " " Westinghouse | 3 | 35 |
| " boxes | 3 | 33 |
| " " Location of | 3 | 44 |
| " Selection of proper size of | 3 | 42 |
| Fuses, Substitutes for | 3 | 43 |
| " Twisted | 3 | 42 |

**G.**

| | Sec. | Page. |
|---|---|---|
| G. E. 52 armature | 8 | 40 |
| G. E. 800 armature | 8 | 43 |
| G. E. 1000 armature | 8 | 6 |
| G. E. 800 bearings | 8 | 44 |
| G. E. 1000 bearings | 8 | 19 |
| G. E. 52 brush holder | 8 | 41 |
| G. E. 1000 brush holder | 8 | 14 |
| G. E. 1000 commutator | 8 | 9 |
| G. E. 52 field coils | 8 | 40 |
| G. E. 800 field coils | 8 | 43 |
| G. E. 1000 field coils | 8 | 4 |
| G. E. 52 frame | 8 | 36 |
| G. E. 800 frame | 8 | 42 |
| G. E. 1000 frame | 8 | 1 |
| G. E. 1000 gearing | 8 | 22 |
| G. E. 52 gears | 8 | 41 |
| G. E. 800 gears | 8 | 44 |
| G. E. 52 motor, Rating of | 8 | 33 |
| G. E. 52 pole pieces | 8 | 38 |
| G. E. 800 shunt | 8 | 44 |
| G. E. 800 speed | 8 | 44 |
| Garton arrester, Connections for | 4 | 3 |
| " lightning arrester | 4 | 1 |
| Gear, How to put on | 8 | 29 |
| " reduction, Change in | 8 | 27 |
| " " Effect of changing | 8 | 24 |
| Gear trouble | 8 | 31 |
| Gearing, G. E. 1000 | 8 | 22 |
| " Johnson No. 20 motor | 12 | 8 |
| " " No. 34 motor | 12 | 13 |
| " Walker 30 H. P. | 11 | 10 |
| " Westinghouse No. 3. | 10 | 15 |
| Gears, G. E. 52 | 8 | 41 |
| " G. E. 800 | 8 | 44 |
| General description, K2 controller | 9 | 3 |
| " Electric arrester, Connections for | 4 | 17 |
| " " canopy switch | 3 | 28 |
| " " controllers, Classification of | 9 | 1 |
| " " fuse box | 3 | 37 |
| " " lightning arrester | 4 | 12 |
| " " lightning arrester, Early type | 4 | 14 |
| " " 52 motor | 8 | 33 |
| " " 800 motor | 8 | 42 |
| " " 1000 motor | 8 | 1 |
| " " resistance coil | 4 | 28 |
| " " shunt | 4 | 32 |
| " remarks on lightning arresters | 4 | 15 |
| " " on loops | 5 | 17 |
| Generation of E. M. F | 2 | 1 |
| " " " Conditions required for | 7 | 28 |
| Ground on shunt | 6 | 12 |
| " " the loop wire | 6 | 10 |
| Grounds in armature | 6 | 5 |
| " " connection with 28A controller | 10 | 42 |
| " " connection with Walker type S controller | 11 | 41 |
| " on K2 controller wiring | 9 | 40 |

**H.**

| | Sec. | Page. |
|---|---|---|
| Handling motors | 2 | 9 |
| Harp, The | 3 | 4 |
| Heating of motor | 1 | 28 |
| Hood switches (see "canopy switches"). | | |
| Horsepower | 8 | 33 |
| 30 H. P. equipment, Copper fuses for | 3 | 34 |
| 50 H. P. equipment, Copper fuses for | 3 | 34 |
| Horseshoe magnet | 1 | 11 |
| How to put on a gear | 8 | 29 |

| I. | Sec. | Page. |
|---|---|---|
| Induction | 2 | 19 |
| " Mutual | 2 | 20 |
| " Simple | 2 | 19 |
| " Three kinds of | 2 | 19 |
| Inductive discharge, Cause of | 2 | 28 |
| " " Precautions against | 2 | 29 |
| " " The | 2 | 28 |
| " effects in motor circuits, Examples of | 2 | 31 |
| Inspection of lightning arresters | 4 | 15 |
| Installation of lightning arresters | 4 | 16 |
| Interlocking device, K2 controller | 9 | 5 |
| " device, Walker type S controller | 11 | 15 |
| Internal connections, Johnson type 34 controller | 12 | 18 |
| " connections of 28A controller | 10 | 27 |
| " connections, Walker type S controller | 11 | 20 |

| J. | Sec. | Page. |
|---|---|---|
| Johnson canopy switch | 3 | 31 |
| " controllers | 12 | 13 |
| " fuse box | 3 | 38 |
| " motor | 12 | 1 |
| " No. 20 motor | 12 | 1 |
| " No. 34 motor | 12 | 8 |
| " No. 20 motor armature | 12 | 4 |
| " No. 34 motor armature | 12 | 11 |
| " No. 20 motor bearings | 12 | 8 |
| " No. 34 motor bearings | 12 | 13 |
| " No. 20 motor brush holder | 12 | 7 |
| " No. 34 motor brush holder | 12 | 13 |
| " No. 20 motor field coil | 12 | 6 |
| " No. 34 motor field coil | 12 | 11 |
| " No. 20 motor frame | 12 | 2 |
| " No. 34 motor frame | 12 | 9 |
| " No. 20 motor gearing | 12 | 8 |
| " No. 34 motor gearing | 12 | 13 |
| " resistance coil | 4 | 30 |
| " shunt | 4 | 32 |
| " trolley base | 3 | 13 |
| " type 34 controller, Combination reverse switch and cut-out | 12 | 17 |
| " type 34 controller, Internal connections | 12 | 18 |
| " type 34 controller, Power drum | 12 | 13 |
| " type 34 controller, Starting-coil connections | 12 | 22 |

| K. | Sec. | Page. |
|---|---|---|
| K2 controller | 9 | 3 |
| " " Car-wiring diagram | 9 | 28 |
| " " Connecting board | 9 | 25 |
| " " Details of cut-out switch | 9 | 21 |
| " " General description | 9 | 3 |
| " " Interlocking device | 9 | 5 |
| " " Motor cut-out | 9 | 19 |
| " " Notches | 9 | 15 |
| " " Open circuits in wiring | 9 | 35 |
| " " Power drum | 9 | 9 |
| " " Reverse drum | 9 | 17 |
| " " Troubles in connection with | 9 | 32 |
| " " wiring, Grounds on | 9 | 40 |
| K11 controller | 9 | 45 |
| Kicking coils, Use of | 4 | 21 |

| L. | Sec. | Page. |
|---|---|---|
| Lessening the shock from series to parallel | 2 | 15 |
| Lightning arrester, Ajax | 4 | 5 |
| " " Garton | 4 | 1 |
| " " General Electric | 4 | 12 |
| " " Principles of | 2 | 24 |
| " " The | 2 | 24 |
| " " Wurts non-arcing | 4 | 10 |
| " arresters, Inspection of | 4 | 15 |
| " " Installation of | 4 | 16 |
| " " Protection afforded by | 4 | 22 |
| Location of fuse boxes | 3 | 44 |
| Loop and shunt, The | 2 | 7 |
| " Explanation of | 2 | 8 |
| " field, Open circuit on | 6 | 26 |
| " wire, Ground on | 6 | 10 |
| Loops and shunts, Distinction between | 5 | 17 |
| " General remarks on | 5 | 17 |
| " Short circuits and open circuits on | 5 | 19 |
| Losses in motor | 8 | 35 |

| M. | Sec. | Page. |
|---|---|---|
| Magnet, Bar | 1 | 13 |
| " core | 1 | 17 |
| " Horseshoe | 1 | 11 |
| " Multiple horseshoe | 1 | 13 |

| | Sec. | Page. |
|---|---|---|
| Magnet, Ring | 1 | 13 |
| " Street-car motor | 1 | 14 |
| Magnetic blow-out | 2 | 27 |
| " circuit, Closed | 1 | 13 |
| Magnets, Types of | 1 | 11 |
| Molding, Running wire in | 3 | 24 |
| Motor connections | 1 | 27 |
| " current, Determination of | 3 | 35 |
| " cut-out, K2 controller | 9 | 19 |
| " field with shunt | 2 | 9 |
| " Heating of | 1 | 28 |
| " Johnson | 12 | 1 |
| " " No. 20 | 12 | 1 |
| " rotation | 1 | 19 |
| " Walker 30 H. P | 11 | 1 |
| " Westinghouse | 10 | 1 |
| " " 12A | 10 | 16 |
| " " No. 3 | 10 | 1 |
| Motors, Braking action of | 7 | 30 |
| " Handling of | 2 | 9 |
| " in parallel | 2 | 11 |
| " " series | 2 | 11 |
| " Losses in | 8 | 35 |
| " Using, as a brake | 7 | 27 |
| Multiple control, Old-rheostat | 7 | 14 |
| " horseshoe magnet | 1 | 13 |
| Mutual induction | 2 | 20 |

**N.**

| | Sec. | Page. |
|---|---|---|
| Notches and positions, Walker type S controller | 11 | 28 |
| " K2 controller | 9 | 15 |
| Nuttall trolley stand | 3 | 9 |

**O.**

| | Sec. | Page. |
|---|---|---|
| Objections to shunts | 5 | 14 |
| Ohm | 1 | 7 |
| " Application of | 1 | 8 |
| Ohmic and spurious resistance | 2 | 5 |
| Ohm's law | 1 | 9 |
| Old-rheostat control | 5 | 1 |
| " " " Connections for | 5 | 5 |
| " " " Field next to ground | 6 | 9 |
| " " " Grounds on | 5 | 23 |
| " " " " " | 6 | 1 |
| " " " Open circuit | 6 | 13 |
| " " " Use of loop | 5 | 8 |
| " " " Use of reverse switch | 5 | 7 |
| " " " Use of shunt | 5 | 10 |
| " " " Wrong connections | 7 | 1 |
| " " multiple control | 7 | 14 |
| Old-rheostat series control | 7 | 45 |
| Open circuit at brushes | 6 | 18 |
| " " in armature | 6 | 22 |
| " " " field | 6 | 24 |
| " " " " wiring K2 controller | 9 | 35 |
| " " on loop field | 6 | 26 |
| " " " shunted field | 6 | 27 |
| " circuits | 6 | 13 |
| Operation of emergency brake position, Walker type S controller | 11 | 29 |
| Overloading motors and resistances, Effects of | 4 | 27 |

**P.**

| | Sec. | Page. |
|---|---|---|
| Permanent loop or shunt | 5 | 21 |
| Picking up of dynamo | 7 | 27 |
| Pole pieces, G. E. 52 | 8 | 38 |
| " socket | 3 | 8 |
| " Trolley | 3 | 2 |
| Poles, Charged | 4 | 23 |
| Poor bonding, Effects of | 6 | 19 |
| Power drum, Johnson type 34 controller | 12 | 13 |
| " " K2 controller | 9 | 9 |
| " " Walker type S controller | 11 | 16 |
| " Throwing off of | 2 | 9 |
| Precautions against inductive discharge | 2 | 29 |
| Principle of Ajax arrester | 4 | 8 |
| Protection afforded by arresters | 4 | 22 |
| Pump and dynamo | 1 | 2 |

**Q.**

| | Sec. | Page. |
|---|---|---|
| Quick handling, Effect of | 2 | 18 |

**R.**

| | Sec. | Page. |
|---|---|---|
| Rails, Dead | 6 | 19 |
| " Dusty | 6 | 17 |
| Rating of motor | 8 | 33 |
| Relation between frog and trolley | 3 | 17 |
| " " speed and resistance | 7 | 28 |
| Resistance | 1 | 7 |
| " coil, General Electric | 4 | 28 |
| " " Johnson | 4 | 30 |
| " " Westinghouse | 4 | 29 |
| " coils | 4 | 25 |
| " " Arrangement of, for increased current | 4 | 28 |
| " " Reasons for use of | 4 | 25 |
| " Cutting out | 2 | 17 |

| | Sec. | Page. |
|---|---|---|
| Resistance notches, Running cars on | 4 | 26 |
| " offered by counter E. M. F. | 2 | 14 |
| " Ohmic and spurious | 2 | 5 |
| Resistances in series and parallel | 2 | 14 |
| Reverse drum, K2 controller | 9 | 17 |
| " switch | 1 | 22 |
| " " and cut-out connections, Walker type S controller | 11 | 29 |
| " " 28A controller | 10 | 23 |
| " " Thomson-Houston | 1 | 22 |
| " " Walker type S controller | 11 | 14 |
| Ring magnet | 1 | 13 |
| Rotation, Motor | 1 | 19 |
| Running cars on resistance notches | 4 | 26 |
| " wire in molding | 3 | 24 |

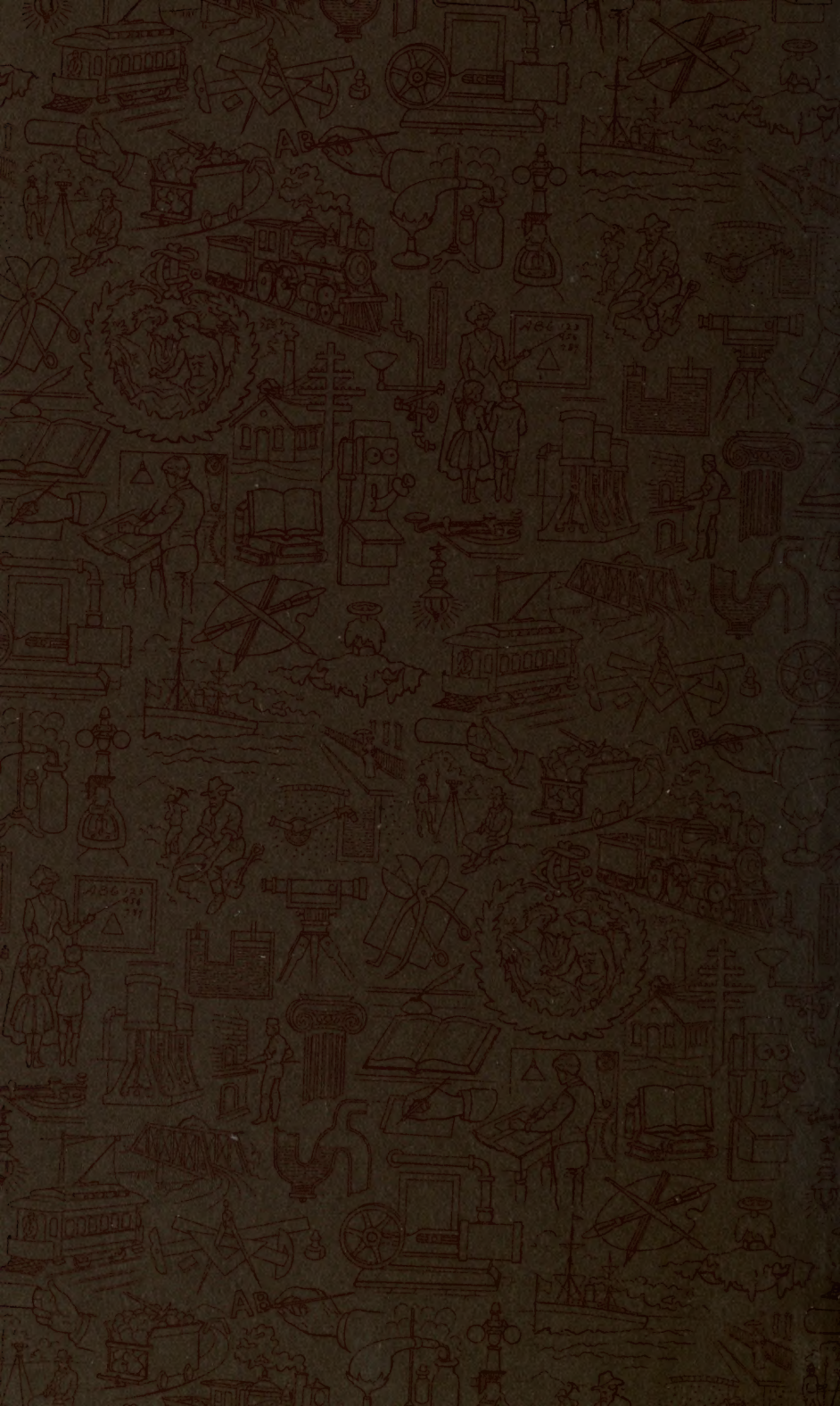
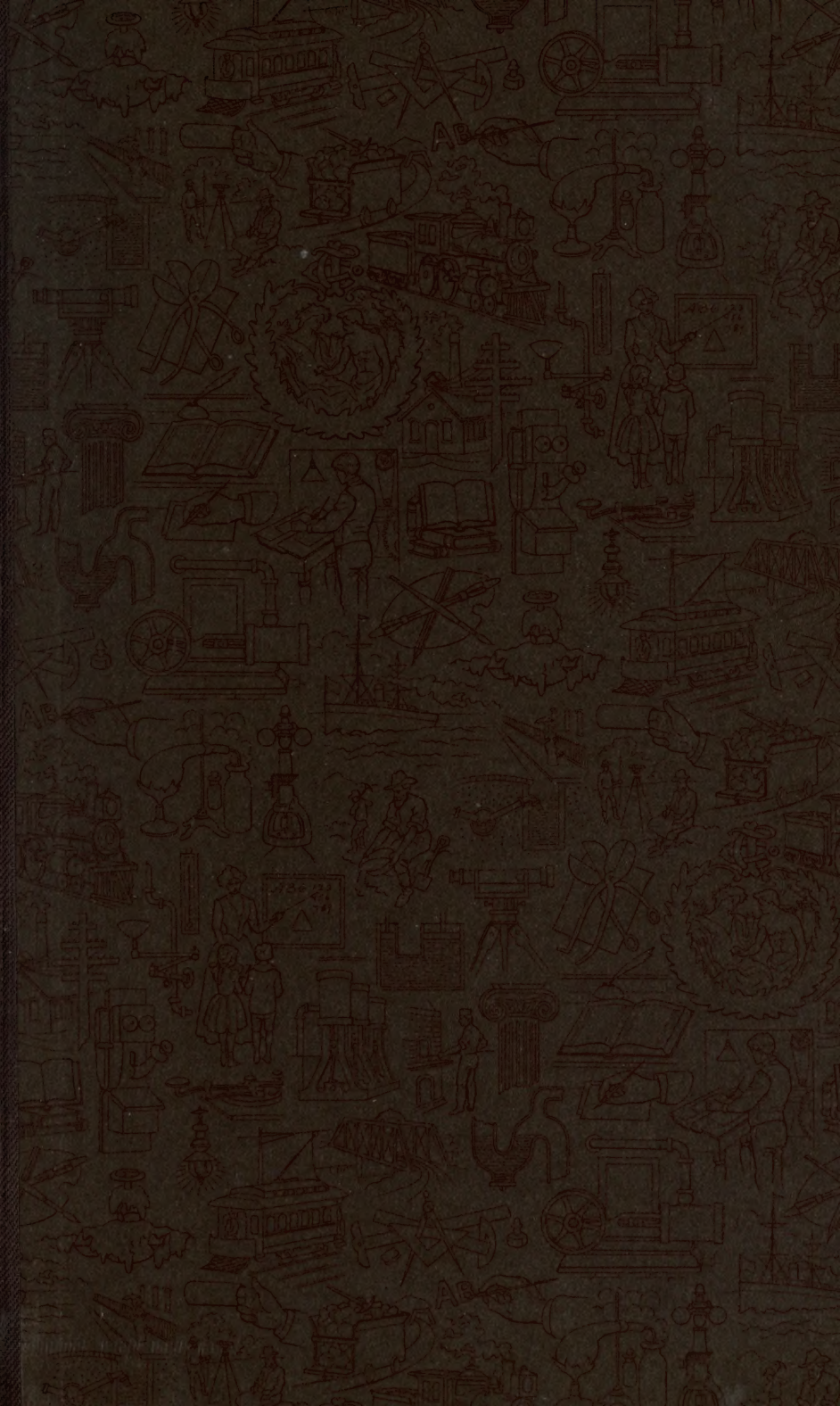
| S. | Sec. | Page. |
|---|---|---|
| Segments, Commutator | 1 | 25 |
| Selection of proper size of fuse | 3 | 42 |
| Self-induction | 2 | 22 |
| " " in straight wires and spirals | 2 | 23 |
| Series and multiple control, Difference between | 7 | 45 |
| " control, Old rheostat | 7 | 45 |
| " cut-out and multiple cut-out | 7 | 47 |
| " " " Type of | 7 | 48 |
| Shifting brushes | 6 | 3 |
| Shunt, Explanation of | 2 | 7 |
| " G. E. 800 | 8 | 44 |
| " General Electric | 4 | 32 |
| " Ground on | 6 | 12 |
| " Johnson | 4 | 32 |
| " Motor field with | 2 | 9 |
| Shunts | 4 | 31 |
| " Advantages of | 5 | 12 |
| " Faults in | 5 | 15 |
| " Objections to | 5 | 14 |
| " Use of | 4 | 31 |
| Shunted field, Open circuit on | 6 | 27 |
| Simple canopy switch | 3 | 26 |
| " commutator | 1 | 24 |
| " induction | 2 | 19 |
| " trolley stand | 3 | 8 |
| Single motor, Double-end control of | 7 | 10 |
| Size of trunk wire | 3 | 25 |
| Slow running cars | 5 | 15 |
| " " Causes of | 5 | 15 |
| Socket, Pole | 3 | 8 |
| Solenoid | 1 | 15 |
| Speed and counter E. M. F. | 2 | 6 |
| " " resistance, Relation between | 7 | 28 |
| " G. E. 800 | 8 | 44 |
| Spiral or solenoid | 1 | 15 |
| Stand, Simple trolley | 3 | 8 |
| Stands, Trolley | 3 | 7 |
| Starting-coil connections, Johnson type 34 controller | 12 | 22 |
| Street-car motor magnet | 1 | 14 |
| Substitutes for fuses | 3 | 43 |
| Suspension, Walker 30 H. P. | 11 | 10 |
| Switch, Reverse | 1 | 22 |
| Switches, Canopy | 3 | 25 |

| T. | Sec. | Page. |
|---|---|---|
| T. H. rheostat, General description of | 5 | 2 |
| T. H. trolley stand | 3 | 11 |
| Thomson-Houston reverse switch | 1 | 22 |
| Three kinds of induction | 2 | 19 |
| Throwing from series to parallel | 2 | 11 |
| " off the power | 2 | 9 |
| Trolley base, Anderson | 3 | 15 |
| " " Duncan | 3 | 15 |
| " " Johnson | 3 | 13 |
| " bridge | 3 | 21 |
| " Care of | 3 | 20 |
| " contact springs | 3 | 5 |
| " Directions for mounting and oiling | 3 | 20 |
| " pole | 3 | 2 |
| " stand, Nuttall | 3 | 9 |
| " " T. H. | 3 | 11 |
| " stands | 3 | 7 |
| " The | 3 | 2 |
| " wheel | 3 | 5 |
| Trunk wire, Size of | 3 | 25 |
| " wiring | 3 | 22 |
| " " Details relating to | 3 | 24 |
| Twisted fuses | 3 | 42 |
| Two dynamos in opposition | 7 | 29 |
| Type 34 Johnson controller | 12 | 13 |
| Types of magnets | 1 | 11 |

| U. | Sec. | Page. |
|---|---|---|
| Units, Electrical | 1 | 1 |
| " of power, Electrical and mechanical | 8 | 34 |
| Use of fuse box | 3 | 33 |
| " " kicking coils | 4 | 21 |
| " " shunts | 4 | 31 |
| Uses of controllers | 9 | 2 |
| Using the motors as a brake | 7 | 27 |

| V. | Sec. | Page. |
|---|---|---|
| Variation of current with resistance | 1 | 10 |
| " " " " voltage.. | 1 | 9 |
| Volt | 1 | 2 |
| " Application of | 1 | 4 |
| Voltage | 1 | 2 |

| W. | Sec. | Page. |
|---|---|---|
| Walker fuse box | 3 | 38 |
| " 30 H. P. armature | 11 | 6 |
| " " " " bearings | 11 | 10 |
| " " " " brush holder | 11 | 8 |
| " " " " field coil | 11 | 7 |
| " " " " frame | 11 | 1 |
| " " " " gearing | 11 | 10 |
| " " " " motor | 11 | 1 |
| " " " " suspension | 11 | 10 |
| " type S controller | 11 | 13 |
| " type S controller combination cut-out | 11 | 21 |
| " type S controller current paths and combinations | 11 | 24 |
| " type S controller, Grounds in connection with | 11 | 41 |
| " type S controller interlocking device | 11 | 15 |
| " type S controller internal connections | 11 | 20 |
| " type S controller, Notches and positions in | 11 | 28 |
| " type S controller, Operation of emergency brake position | 11 | 33 |
| " type S controller power drum | 11 | 16 |
| Walker type S controller reverse switch | 11 | 14 |
| " type S controller reverse switch and cut-out connections | 11 | 29 |
| Westinghouse 12A armature | 10 | 19 |
| " arrester, Connections for | 4 | 16 |
| " No. 3 armature and commutator | 10 | 6 |
| " No. 3 armature connections | 10 | 7 |
| " No. 3 bearings | 10 | 6 |
| " No. 3 brush holder | 10 | 14 |
| " 12A brush holder | 10 | 20 |
| " canopy switch | 3 | 27 |
| " 28A controller | 10 | 20 |
| " 12A field | 10 | 20 |
| " No. 3 field coil | 10 | 11 |
| " 12A frame | 10 | 17 |
| " fuse box | 3 | 35 |
| " No. 3 gearing | 10 | 15 |
| " motor | 10 | 1 |
| " No. 3 motor | 10 | 1 |
| " 12A motor | 10 | 16 |
| " No. 3 motor, How to handle, in pit | 10 | 4 |
| " resistance coil | 4 | 29 |
| Wheel, Trolley | 3 | 5 |
| Wiring, Trunk | 3 | 22 |
| Wrong connections of old rheostat control | 7 | 1 |
| " field connections | 10 | 13 |
| Wurts lightning arrester, Connections for | 4 | 12 |
| " non-arcing lightning arrester | 4 | 10 |

LIBRARY
AUG 1 3 1993
UNIVERSITY OF TORONTO

LIBRARY
USE UNTIL
FEB 2 4 1994
ENGINEERING